EPA/NSF ETV PROTOCOL

PROTOCOL FOR EQUIPMENT VERIFICATION TESTING FOR REMOVAL OF PRECURSORS TO DISINFECTION BY-PRODUCTS

Engineering & Research Services

NSF International • Ann Arbor, Michigan

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Recommended by
the Steering Committee for the Verification of
Package Drinking Water Treatment Systems/Plants
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Environmental Technology Verification Program

NSF INTERNATIONAL

Mission Statement:
NSF International (NSF), an independent, not-for-profit organization, is dedicated to public health safety and protection of the environment by developing standards, by providing education and providing superior third party conformity assessment services while representing the interests of all stakeholders.

NSF Purpose and Organization
NSF is an independent not-for-profit organization. For more than 52 years, NSF has been in the business of developing consensus standards that promote and protect public health and the environment and providing testing and certification services to ensure manufacturers and users alike that products meet those standards. Today, millions of products bear the NSF Name, Logo and/or Mark, symbols upon which the public can rely for assurance that equipment and products meet strict public health and performance criteria and standards.

Limitations of use of NSF Documents
This protocol is subject to revision; contact NSF to confirm this revision is current. The testing against this protocol does not constitute an NSF Certification of the product tested.

U.S. ENVIRONMENTAL PROTECTION AGENCY

Throughout its history, the U.S. Environmental Protection Agency (EPA) has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. EPA is now expanding these efforts by instituting a new program, the Environmental Technology Verification Program---or ETV---to verify the performance of a larger universe of innovative technical solutions to problems that threaten human health or the environment. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. It supplies technology buyers and developers, consulting engineers, states, and U.S. EPA regions with high quality data on the performance of new technologies. This encourages more rapid availability of approaches to better protect the environment.

ETV's Package Drinking Water Treatment Systems Pilot Project:

Concern about drinking water safety has accelerated in recent years due to much publicized outbreaks of waterborne disease and information linking ingestion of high levels of disinfection byproducts to cancer incidence. The U.S. EPA is authorized through the Safe Drinking Water Act to set numerical contaminant standards and treatment and monitoring requirements that will ensure the safety of public water supplies. However, small communities are often poorly equipped to comply with all of the requirements; less costly package treatment technologies may offer a solution. These package plants can be designed to deal with specific problems of a particular community; additionally, they may be installed on site more efficiently---requiring less start-up capital and time than traditionally constructed water treatment plants. The opportunity for the sales of such systems in other countries is also substantial.

The U.S. EPA has partnered with NSF, a nonprofit testing and certification organization, to verify performance of small package drinking water systems that serve small communities. It is expected that both the domestic and international markets for such systems are substantial. EPA and NSF have formed an oversight stakeholders group composed of buyers, sellers, and states (issuers of permits), to assist in formulating consensus testing protocols. A goal of verification testing is to enhance and facilitate the acceptance of small package drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment use is contemplated. NSF will meet this goal by working with equipment Manufacturers and other agencies in planning and conducting equipment verification testing, evaluating data generated by such testing and managing and disseminating information. The Manufacturer is expected to secure the appropriate resources to support their part of the equipment verification process, including provision of equipment and technical support.

The verification process established by EPA and NSF is intended to serve as a template for conducting water treatment verification tests that will generate high quality data for verification of equipment performance. The verification process is a model process that can help in moving small package drinking water equipment into routine use more quickly. The verification of an equipment's performance involves five sequential steps:

1. Development of a verification/Field Operations Document;
2. Execution of verification testing;
3. Data reduction, analysis, and reporting;
4. Performance and cost (labor, chemicals, energy) verification;
5. Report preparation and information transfer.

This verification testing program is being conducted by NSF International with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division (WSWRD) - Cincinnati, Ohio. NSF's role is to provide technical and administrative leadership and support in conducting the testing. It is important to note that verification of the equipment does not mean that the equipment is “certified” by NSF or EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations.

Partnerships:
The U.S. EPA and NSF are cooperatively organizing and developing the ETV’s Package Drinking Water Treatment Systems Pilot Project to meet community and commercial needs. NSF and the Association of State Drinking Water Administrators have an understanding to assist each other in promoting and communicating the benefits and results of the project.

ORGANIZATION AND INTENDED USE OF PROTOCOL AND TEST PLANS

NSF encourages the user of this protocol to also read and understand the policies related to the verification and testing of package drinking water treatment systems and equipment.

The first Chapter of this document describes the Protocol required in all studies verifying the performance of equipment or systems removing precursors to disinfection by-products, the public health goal of the Protocol. The remaining chapters describe the additional requirements for equipment and systems using specific technologies to attain the goals and objectives of the Protocol: the removal of precursors to disinfection by-products.

Prior to the verification testing of a package drinking water treatment systems, plants and/or equipment, the equipment manufacturer and/or supplier must select an NSF-qualified Field Testing Organization (FTO). This designated Field Testing Organization must write a "Field Operations Document" (FOD). The equipment manufacturer and/or supplier will need this protocol and the test plans herein and other NSF Protocols and Test Plans to develop the Field Operations Document depending on the treatment technologies used in the unit processes or treatment train of the equipment or system. More than one protocol and/or test plan may be necessary to address the equipment's capabilities in the treatment of drinking water.

Testing shall be conducted by an NSF-qualified Field Testing Organization that is selected by the Manufacturer. Water quality analytical work to be completed as a part of an NSF Equipment Verification Testing Plan shall be contracted with a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA. For information on a listing of NSF-qualified FTOs and State, third-party organization (i.e., NSF), or the U.S. EPA-accredited laboratories, contact NSF.

ACKNOWLEDGMENTS

The U.S. EPA and NSF International would like to acknowledge those persons who participated in the preparation, review and approval of this Protocol. Without their hard work and dedication to the project, this document would not have been approved through the process which has been set forth for this ETV project.

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CHAPTER 1

EPA/NSF ETV PROTOCOL FOR EQUIPMENT VERIFICATION TESTING OF DISINFECTION BY-PRODUCT PRECURSOR REMOVAL

REQUIREMENTS FOR ALL STUDIES

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1.0 INTRODUCTION

This document is the study protocol to be used for verification testing of equipment designed to achieve removal of precursors to disinfection by-products (DBPs). The equipment Field Testing Organization (FTO) must adhere to the requirements of this study protocol in developing a Field Operations Document (FOD).

The testing of new technologies and materials that are unfamiliar to the NSF/EPA will not be discouraged. It is recommended that resins or membranes or any other material or chemical in the package plant conform to American National Standards Institute/NSF International (ANSI/NSF) Standard 60 and 61.

The final submission of the FOD shall:

- include the information requested in this protocol;
- conform to the format identified herein; and
- conform to the specific NSF International (NSF) Equipment Verification Testing Plan or Plans related to the statement or statements of capabilities that are to be verified.

The FOD may include more than one Testing Plan. Equipment testing might be undertaken to verify performance of a packaged plant systems employing processes that may include but are not limited to coagulation/clarification, oxidation or mixed oxidation processes, adsorption, biological filtration or membrane filtration for removal of DBP precursors.

This protocol document is presented in two fonts. The non-italicized font provides the rationale for the requirements and background information that the Field Testing Organization may find useful in preparation of the FOD. *The italicized text indicates specific study protocol deliverables that are required of the Field Testing Organization or of the Manufacturer and that must be incorporated in the FOD.*

The following glossary terms are presented here for subsequent reference in this protocol:

- Distribution System - a system of conduits by which a primary potable water supply is conveyed to consumers, typically by a network of pipelines.
- EPA - The United States Environmental Protection Agency, its staff or authorized representatives
- Equipment - Testing equipment for use in the Verification Testing Program which may be defined as either a package plant or modular system.
- Field Operations Document - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.

- Field Testing Organization - An organization qualified to conduct studies and testing of package plants or modular systems in accordance with protocols and test plans. The role of the Field Testing Organization is to complete the application on behalf of the company; to enter into contracts with NSF, as discussed herein, arrange for or conduct the skilled operation of a package plant during the intense period of testing during the study and the tasks required by the protocol.
- Manufacturer - a business that assembles and/or sells package plant equipment and/or modular systems. The role of the Manufacturer is to provide the package plant and/or modular system and technical support during the Verification Testing Program. The Manufacturer is also responsible for providing assistance to the third party Field Testing Organization during operation and monitoring of the package plant or modular system in the Verification Testing Program.
- Modular System - A packaged functional assembly of components for use in a drinking water treatment system or packaged plant, that provides a limited form of treatment of the feed water(s) and which is discharged to another packaged plant module or the final step of treatment to the distribution system.
- NSF - NSF International, its staff, or other authorized representatives.
- Packaged plant - a complete water treatment system including all components from connection to the raw water(s) through discharge to the distribution system.
- Plant Operator - the person working for a small water system who is responsible for operating packaged water treatment equipment to produce treated drinking water. This person may also collect samples, record data and attend to the daily operations of equipment throughout the testing periods.
- Protocol - A written document that clearly states the objectives, goals, and scope of the study as well as the test plan(s) for the conduct of the study. Protocol will be used for reference during Manufacturer participation in Verification Testing Program.
- Report - A written document that includes data, test results, findings, and any pertinent information collected in accordance with a protocol, analytical methods, procedures, etc., in the assessment of a product whether such information is preliminary, draft or final form.
- Testing Plan - A written document that describes the procedures for conducting a test or study for the application of water treatment technology. At a minimum, the test plan will include detailed instructions for sample and data collection, sample handling and sample preservation, precision, accuracy, and reproducibility goals, and quality assurance and quality control requirements.
- Testing Laboratory - An organization certified by a third-party independent organization, federal agency, or a pertinent state regulatory authority to perform the testing of drinking water samples. The role of the testing laboratory in the verification testing of package plants and/or modular systems is to analyze the water samples in accordance with the methods and meet the pertinent quality assurance and quality control requirements described in the protocol, test plan and FOD.
- Verification - to establish the evidence on the range of performance of equipment and/or device under specific conditions following a predetermined study protocol.

- Verification Statement -A written document that summarizes a final report reviewed and approved by NSF on behalf of the EPA or directly by the EPA
- Water System - the water system that operates using packaged water treatment equipment to provide potable water to its customers.

1.1 Objectives

The specific objectives of verification testing may be different for each package plant or modular system, depending upon the statement of capabilities of the specific equipment to be tested. The objectives developed by each Manufacturer will be defined and described in detail in the FOD developed for each piece of equipment. The objectives of the Equipment Verification Testing Program may include:

- Generation of field data appropriate for verifying the performance of the equipment;
- Generation of field data in support of meeting current or anticipated water quality regulations;
- Evaluation of new advances in equipment and equipment design.

An important aspect in the development of verification testing is to describe the procedures that will be used to verify the statement of performance capabilities made for water treatment equipment. A verification testing plan document shall incorporate the quality assurance (QA) and quality control (QC) elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the equipment performance. Verification testing conducted at a single site may not represent every environmental situation which may be acceptable for the equipment tested, but it will provide data of sufficient quality to make a judgment about the application of the equipment under conditions similar to those encountered in the verification testing.

1.2 Scope

This protocol outlines the verification process for equipment designed to achieve removal of precursors to DBPs. The scope of this protocol includes testing plans for packaged and/or modular drinking water treatment systems designed to achieve removal of DBP precursors.

An overview of the verification process and the elements of the FOD to be developed by the Field Testing Organization are described in this protocol. Specifically, the FOD shall define the following elements of the verification testing:

- Roles and responsibilities of verification testing participants;
- Procedures governing verification testing activities such as equipment operation and process monitoring; sample collection, preservation, and analysis; and data collection and interpretation;
- Experimental design of the Field Operations Procedures;

- QA/QC procedures for conducting the verification testing and for assessing the quality of the data generated from the verification testing; and,
- Health and safety measures relating to biohazard, electrical, mechanical and other safety codes.

Content of Field Operations Document:

The structure of the FOD must conform to the outline below: The required components of the Document will be described in greater detail in the sections below.

- *TITLE PAGE*
- *FOREWORD*
- *TABLE OF CONTENTS - The Table of Contents for the FOD should include the headings provided in this document although they may be modified as appropriate for a particular type of equipment to be tested.*
- *EXECUTIVE SUMMARY - The Executive Summary describes the contents of the FOD (not to exceed two pages). A general description of the equipment and the statement of performance capabilities which will be verified during testing shall be included, as well as the testing locations, a schedule, and a list of participants.*
- *ABBREVIATIONS AND ACRONYMS - A list of the abbreviations and acronyms used in the FOD should be provided.*
- *EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES (described in the sections below)*
- *EQUIPMENT CAPABILITIES AND DESCRIPTION (described in the sections below)*
- *EXPERIMENTAL DESIGN (described in the sections below)*
- *FIELD OPERATIONS PROCEDURES (described in the section below)*
- *QUALITY ASSURANCE TESTING PLAN (described in the section below)*
- *DATA MANAGEMENT AND ANALYSIS (described in the section below)*
- *SAFETY PLAN (described in the section below)*

2.0 EQUIPMENT VERIFICATION TESTING RESPONSIBILITIES

2.1 Verification Testing Organization and Participants

The required content of the FOD and the responsibilities of participants are listed at the end of each section. In the development of a FOD, Manufacturers and their designated Field Testing Organization shall provide a table including the name, affiliation, and mailing address of each participant, a point of contact, description of participant's role, telephone and fax numbers, and e-mail address.

2.2 Organization

The organizational structure for the verification testing showing lines of communication shall be provided by the Field Testing Organization in its application on behalf of the Manufacturer.

2.3 Verification Testing Site Name and Location

This section discusses background information on the verification testing site(s), with emphasis on the quality of the feedwater, which in some cases may be the source water at the site. The FOD must provide the site names and locations at which the equipment will be tested. In most cases, the equipment will be demonstrated at more than one site. In all cases the equipment should be tested under different conditions of feedwater quality (or source water quality) and a range of seasonal climate and weather conditions.

2.4 Site Characteristics

The FOD must include a description of the test site. This shall include a description of where the equipment will be located. If the feedwater to the packaged plant is the source water for an existing water treatment plant, describe the raw water intake, the opportunity to obtain raw water without the addition of any chemicals, and the operational pattern of raw water pumping at the full-scale facility (is it continuous or intermittent?). The source water characteristics shall be described and documented. The FOD shall also describe facilities to be used for handling the treated water and wastes (i.e., residuals) produced during the Verification Testing. Can the required water flows and waste flows produced be dealt with in an acceptable way? Are water pollution discharge permits needed?

2.5 Responsibilities

This section identifies the organizations involved in the testing and describes the primary responsibilities of each organization. The responsibilities of the Manufacturer will vary depending on the type of verification testing. Multiple Manufacturer testing for removal of DBP precursors may be conducted concurrently, and be fully in compliance with the NSF Equipment Verification Testing Program.

The Field Testing Organization shall be responsible for:

- Providing needed logistical support, establishing a communication network, and scheduling and coordinating the activities of all verification testing participants;
- Advising the Manufacturer on feedwater quality and test site selection, such that the locations selected as test sites have feedwater quality consistent with the objectives of the verification testing (Manufacturer may recommend a verification testing site(s));
- Managing, evaluating, interpreting, and reporting on data generated by the verification testing;
- Evaluating and reporting on the performance of the DBP precursor removal technologies.

The Manufacturer shall be responsible for provision of the equipment to be evaluated.

Content of FOD Regarding Equipment Verification Testing Responsibilities:

The Field Testing Organization shall be responsible for including the following elements in the FOD:

- *Definition of the roles and responsibilities of appropriate verification testing participants*
- A *table which includes the name, affiliation, and mailing address of each participant, a point of contact, description of participant's role, telephone and fax numbers, and e-mail address.*
- *Organization of operational and analytical support*
- *List of the site name(s) and location(s).*
- *Description of the test site(s), the site characteristics and identification of where the equipment will be located.*

Manufacturer Responsibilities:

- *Provision of complete, field-ready equipment for verification testing;*
- *Provision of logistical, and technical support, as required.*
- *Provision of technical assistance to the qualified testing organization during operation and monitoring of the equipment undergoing verification testing.*

3.0 EQUIPMENT CAPABILITIES AND DESCRIPTION

3.1 Equipment Capabilities

The Manufacturer and their designated Field Testing Organization shall identify the water quality objectives to be achieved in the statement of performance capabilities of the equipment to be evaluated in the verification testing. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and what advantages it provides over existing equipment. The statement of performance capabilities must be specific and verifiable by a statistical analysis of the data. Two examples of satisfactory statements of performance capabilities are provided below:

1. "This packaged plant is capable of achieving 40% removal of dissolved organic carbon (DOC) in feedwaters with total organic carbon concentrations between 2.0 and 4.0 mg/L and with feed water alkalinities less than 60 mg/L as $CaCO_3$."

2. "This packaged plant is capable of achieving 40% removal of precursors to trichloroacetic acid (TCA) in feedwaters. Removal of TCA precursors will be quantified by comparison of Simulated Distribution System (SDS) testing results generated for feed and finished water

samples. The following equation shall be used to determine percent removal of all DBP precursors:"

$$\% \text{ Removal Precursor Material} = 100 \times \frac{(\text{feedwater DBP Conc} - \text{Finished Water Conc.})}{\text{Feedwater DBP Conc}}$$

A statement of performance capabilities such as: "This packaged plant will achieve removal of DOC in accordance with the Enhanced Coagulation requirement of the Disinfectants/Disinfection By-Product Rule (D/DBP Rule) on a consistent and dependable basis," would not be acceptable.

The Manufacturer shall be responsible for identification of which DBP precursors shall be monitored for removal under the statement of performance capabilities. The statement of performance capabilities prepared by the Manufacturer shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feed water. Statements of performance capabilities that are too easily met may not be of interest to the potential user, while performance capabilities that are overstated may not be achievable. The statement of performance capabilities forms the basis of the entire Equipment Verification Testing Program and must be chosen appropriately. Therefore, the design of the FOD should include a sufficient range of feedwater quality to permit verification of the statement of performance capabilities.

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in the DBP Precursor Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this DBP Precursor Protocol and the associated Verification Testing Plans are oriented towards removal of DBP precursors, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

3.2 Equipment Description

Description of the equipment for verification testing shall be included in the FOD. Data plates shall be permanent and securely attached to each production unit. The data plate shall be easy to read in English or the language of the intended user, located on the equipment where it is readily accessible, and contain at least the following information:

a. Equipment Name
b. Model #
c. Manufacturer's name and address
d. Electrical requirements - volts, amps, and Hertz
e. Serial Number
f. Warning and Caution statements in legible and easily discernible print size
g. Capacity or output rate (if applicable)

Content of Field Operations Document Regarding Equipment Capabilities and Description:

The FOD shall include the following documents:

- *Description of the equipment to be demonstrated including photographs from relevant angle or perspective;*
- *Brief introduction and discussion of the engineering and scientific concepts on which the DBP precursor removal capabilities of the water treatment equipment are based;*
- *Description of the packaged treatment plant and each process included as a component in the modular system including all relevant schematics;*
- *Brief description of the physical construction/components of the equipment including the general environmental requirements and limitations, required consumables; weight, transportability, ruggedness, power requirements and other relevant requirements for operation, etc.;*
- *Discussion of Statement of typical rates of consumption of chemicals, rates of waste production (concentrates, residues, etc.), characterization of the physical and chemical nature of the waste streams produced by the treatment process, quantification of the water production from routine cleaning, chemical cleaning and other cleaning processes;*
- *Identification of any special licensing requirements associated with the operation of the equipment;*
- *Description of the applications of the equipment and the removal capabilities of the treatment system relative to existing equipment. Comparisons shall be provided in such areas as: treatment capabilities, requirements for chemicals and materials, power, labor requirements, suitability for process monitoring and operation from remote locations, ability to be managed by part-time operators;*
- *Definition of the performance range of the equipment;*
- *Discussion of the known limitations of the equipment. The following operational details shall be included: the range of feed water quality suitable for treatment with the equipment, the upper limits for concentrations of regulated contaminants that can be removed to concentrations below the maximum contaminant level (MCL), the level of operator skill required to successfully use the equipment;*
- *Discussion of the known treatment process incompatibilities of the equipment. A listing shall be provided describing the potentially incompatible treatment processes or chemical additions (i.e., oxidants, coagulants, anti-scalants) that would adversely impact the equipment materials or the treatment process;*
- *Discussion of the potential impacts of the treatment process on other pertinent water quality characteristics, i.e., pH, hardness, alkalinity, corrosivity, Langlier Saturation Index (LSI), etc.*

4.0 EXPERIMENTAL DESIGN

This section discusses the objectives of the verification testing, factors that must be considered to meet the performance objectives, and the statistical analysis and other means that the Field Testing Organization will use to evaluate the results of the verification testing.

4.1 Objectives

The objectives of this verification testing are to evaluate equipment in the following areas: 1) performance relative to the Manufacturer's stated range of equipment capabilities; 2) performance relative to the DBP precursor removal requirements of enhanced coagulation as part of the proposed D/DBP Rule and any other specific or anticipated water quality regulation (i.e., Enhanced Surface Water Treatment Rule); 3) the impacts of variations in feed water quality (such as total organic carbon (TOC), DOC, temperature, turbidity, particle concentration, microbial concentration, pH, alkalinity, etc.) on equipment performance; 4) the logistical, human, and economic resources necessary to operate the equipment; and 5) the reliability, ruggedness, cost, range of usefulness, and ease of operation.

A FOD shall include those treatment tests listed in NSF test plans that are most appropriate to challenge the equipment. For example, if equipment is only intended for removal of DBP precursors, there would be no need to conduct testing to evaluate the removal of hardness ions or metal ion species. However, it should be noted that many of the packaged and/or modular drinking water treatment systems participating in the DBP Precursor Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this protocol for DBP precursor removal and the associated Verification Testing Plans are oriented towards removal of DBP precursors, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

4.2 Equipment Characteristics

This section discusses factors that will be considered in the design and implementation of the Equipment Verification Testing Program. These factors include ease of operation, degree of operator attention required, response of equipment and treatment process to changes in feedwater quality, electrical requirements, system reliability features including redundancy of components, feed flow requirements, discharge requirements, spatial requirements of the equipment (footprint), unit processes included in treatment train and chemicals needed.

Verification testing procedures shall simulate routine conditions as much as possible and in most cases testing may be done in the field. Under such circumstances, simulation of field conditions would not be necessary.

4.2.1 Qualitative Factors

Some factors, while important, are difficult or impossible to quantify. These are considered qualitative factors. Important factors that cannot easily be quantified are the modular nature

of the equipment, the safety of the equipment, the portability of equipment, and the logistical requirements necessary for using it.

Typical qualitative factors to be discussed are listed below, and others may be added. The FOD shall discuss those factors that are appropriate to the test equipment.

- Reliability or susceptibility to environmental conditions
- Equipment safety
- Effect of operator experience on results.

4.2.2 Quantitative Factors

Many factors of the equipment characteristics can be quantified by various means in this Verification Testing Program. Some can be measured while others cannot be controlled. Typical quantitative factors to be discussed are listed below, and others may be added. The FOD shall discuss those factors that are appropriate to the test equipment.

- Power and consumable supply (such as chemical and materials) requirements
- Cost of operation, expendables, and waste disposal
- Hydrodynamics of packaged plant system
- Length of operating cycle.

These quantitative factors will be used as an initial benchmark to assess equipment performance.

4.3 Water Quality Considerations

The primary treatment goal of the equipment employed in this Verification Testing Program is to achieve removal of DBP precursors found in feedwaters (or raw waters) such that product waters are of acceptable water quality (with limited presence of allogenic contaminants). The driving force for the goal of precursor removal is to achieve compliance with the proposed Disinfectant/Disinfection By-Product (D/DBP) Rule and the proposed Groundwater Disinfection Rule under the Safe Drinking Water Act. The experimental design in the FODs shall be developed so the relevant questions about water treatment equipment capabilities can be answered.

Manufacturers should carefully consider the capabilities and limitations of their equipment and prepare FODs that sufficiently challenge their equipment. The Manufacturer should adopt an experimental approach to verification testing that would provide a broad market for their products, while recognizing the limitations of the equipment, and not conducting precursor removal testing that would be beyond the capabilities of the equipment. A wide range of contaminants or water quality problems that can be addressed by water treatment equipment varies, and some packaged treatment equipment can address a broader range of problems than

other types. Manufacturers shall use NSF Equipment Verification Testing Plans as the basis for the specific FODs.

4.3.1 Feedwater Quality

One of the key aspects related to demonstration of equipment performance in the verification testing is the range of feedwater quality that can be treated successfully. The Manufacturer and Field Testing Organization should consider the influence of feedwater quality on the quality of treated waters produced by the packaged plant, such that product waters meet the stated water quality goals (in terms of disinfection by-product concentrations) or regulatory requirements for precursor removals. As the range of feedwater quality that can be treated by the equipment becomes broader, the potential applications for treatment equipment with verified performance capabilities may also increase. Characteristics of feedwater quality that can be important for treatment equipment intended to remove DBP precursors are:

- dissolved organic carbon (DOC), total organic carbon (TOC), or UV-254 absorbance
- biological dissolved organic carbon (BDOC) or assimilable organic carbon (AOC)
- turbidity, particle concentration
- pH and alkalinity
- temperature, with temperatures near freezing having potential for the most difficult treatment conditions
- total dissolved solids (TDS), and other individual inorganic parameters
- presence of background microbial populations including algae, bacteria, viruses and protozoa and other organisms
- Total Kjeldahl Nitrogen (TKN), ammonia nitrogen

One of the questions often asked by regulatory officials in approval of packaged water treatment equipment is: "Has it been shown to work on the water where you propose to put it?" By covering a large range of water qualities the verification testing is more likely to provide an affirmative answer to that question.

4.3.2 Treated Water Quality

Production of treated water of a high quality, with low concentrations of precursors to DBPs shall be the primary goal of the packaged and/or modular water treatment systems included in this Equipment Verification Testing Program. If a Field Testing Organization states that water treatment equipment can be used to treat water to meet specified regulatory requirements for removal of DBP precursors, the verification testing must provide data that support such a statement of capabilities, as appropriate. The statement of capabilities provided by the Field Testing Organization shall be related to the enhanced coagulation requirements of the proposed D/DBP Rule or the proposed Stage 1 DBP maximum contaminant levels. The Field Testing Organization shall be responsible for identification of

the specific DBPs that shall be monitored during the Equipment Verification Testing Program. Water quality analysis for the specific DBPs identified by the Field Testing Organization shall be performed by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA. This issue shall be discussed further in Section 5.2

In addition, the Field Testing Organization may wish to make a statement about performance capabilities of the equipment for removal of other regulated contaminants under the Safe Drinking Water Act (SDWA) that are not directly related to DBP precursor removal. For example, some water treatment equipment can be used to meet aesthetic goals that are not included as regulatory requirements of the SDWA. Removal goals for some of these parameters may also be presented in the Field Testing Organization's statement of capabilities. A number of water quality parameters that may be useful for assessing equipment performance of packaged and/or modular treatment systems are listed below:

- particle count or concentration
- biological dissolved organic carbon (BDOC) or assimilable organic carbon (Standard Methods 9217 A)
- heterotrophic plate count bacteria (HPC)
- color, taste and odor
- total dissolved solids
- hardness ions
- iron and manganese

4.4 Disinfection By-Product Formation Testing

For evaluation of the DBP precursor concentrations, the standardized Information Collection Rule (ICR) approach of the Uniform Formation Conditions (UFC) may be employed in this Verification Testing Program. Alternatively, the conditions selected for SDS evaluation may be those that most closely approximate the detention time and chlorine residual found in the distribution system at the selected location of verification testing. Selected samples shall be prepared for trihalomethane (THM) and haloacetic acid (HAA) analysis using the following procedure which will provide the standardized set of representative chlorination conditions.
The UFC under the ICR stipulate that the following conditions be employed:

- Incubation time: 24 +/- 1 hours
- Incubation temperature: 20.0 +/- 1.0 °C
- Buffered pH: 8.0 +/- 0.2
- 24-hour Chlorine Residual: 1.0 +/- 0.4 mg Cl_2/L

For these conditions, the chlorine dose required to achieve the target chlorine residual can be determined by first conducting a demand study with the water sample. Since the DOC concentrations of a water can vary over the course of a test run, the chlorine demand of a given

water may also vary. The chlorine dose must therefore be varied according to the chlorine demand of the water. Frequency of sampling and SDS DBP analysis shall be specified by the individual test plans used for the Equipment Verification Testing Program and shall also be stipulated in the Manufacturer FOD.

4.5 Recording data

For all DBP precursor experiments, data should be maintained on the pH, temperature, and other water quality parameters listed in Sections 4.3.1 and 4.3.2 above. The following items of information shall also be maintained for each experiment:

- Type of chemical addition, dose and chemical combination, where applicable (e.g., alum, cationic polymer, anionic polymer, ozone, monochloramine, scale inhibitor, etc.);
- Water type (raw water, pretreated feedwater, product water, waste water);
- Experimental run (e.g. 1st run, 2nd run, 3rd run, etc.);

4.6 Recording Statistical Uncertainty

For the analytical data obtained during verification testing, 95% confidence intervals shall be calculated by the Field Testing Organization for selected water quality parameters. The specific testing plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. The following formula shall be employed for confidence interval calculation:

$$\text{confidence interval} = \overline{X} \pm t_{n-1,1-\frac{\alpha}{2}} \left(S / \sqrt{n} \right)$$

where: X is the sample mean;
S is the sample standard deviation;
n is the number of independent measurements included in the data set; and
t is the Student's t distribution value with n-1 degrees of freedom;
α is the significance level, defined for 95% confidence as: 1 - 0.95 = 0.05.

According to the 95% confidence interval approach, the α term is defined to have the value of 0.05, thus simplifying the equation for the 95% confidence interval in the following manner:

$$\text{95\% confidence interval} = \overline{X} \pm t_{n-1,0.975} \left(S / \sqrt{n} \right)$$

With input of the analytical results for pertinent water quality parameters into the 95% confidence interval equation, the output will appear as the sample mean value plus or minus the second term. The results of this statistical calculation may also be presented as a range of values falling within the 95% confidence interval. For example, the results of the confidence interval

calculation may provide the following information: 520 +/- 38.4 mg/L, with a 95% confidence interval range described as (481.6, 558.4).

Calculation of confidence intervals shall not be required for equipment performance results (e.g., filter run length, cleaning efficiency, in-line turbidity or in-line particle counts, etc.) obtained during the equipment testing verification program. However, as specified by the Field Testing Organization, calculation of confidence intervals may be required for such analytical parameters as TOC, DOC, grab samples of turbidity, THMs, HAAs. In order to provide sufficient analytical data for statistical analysis, the Field Testing Organization shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period. The procedures and sampling requirements shall be provided in detail in the Verification Testing Plan.

4.7 Verification Testing Schedule

Verification testing activities include equipment set-up, initial operation, verification operation, and sampling and analysis. Initial operations are intended to be conducted so that equipment can be tested and to be sure it is functioning as intended. If feedwater (or source water) quality influences operation and performance of equipment being tested, the initial operations period serves as the shake-down period for determining appropriate operating parameters. The schedule of testing may also be influenced by coordination requirements with a utility.

For water treatment equipment involving removal of DBP precursors, an initial period of bench-scale testing of feedwater followed by treatment equipment operation may be needed to determine the appropriate operational parameters for testing equipment. A number of operational may require adjustment to achieve successful functioning of the process train; these parameters may include but are not limited to: process rates, feedwater pH, chemical dosages, chemical types where appropriate and equipment operations procedures that will result in successful functioning of the process train.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's claims, such as in the treatment of surface water where additional testing during each season may assist in verifying a claim. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's claims. For example, climatic changes between rainy and dry seasons may produce substantial variability in feedwater turbidity. Cold weather operations may be an important component of seasonal water quality testing because of the impact of cold temperatures (1 °C to 5 °C) on water viscosity, diffusional processes and characteristics of raw water DBP precursor materials. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Content of Field Operations Document Regarding Experimental Design:

The FOD shall include the following elements:

- *Identification of the qualitative and quantitative factors of equipment operation to be addressed in the Verification Testing Program.*
- *Identification and discussion of the particular water treatment issues and dissolved organic carbon concentrations that the equipment is designed to address, how the equipment will solve the problem, and who would be the potential users of the equipment.*
- *Identification of the range of key water quality parameters, given in applicable NSF Testing Plans, which the equipment is intended to address and for which the equipment is applicable.*
- *Identification of the key parameters of treated water quality and analytical methods that will be used for evaluation of equipment performance during the removal of DBP precursors. Parameters of significance for treated water quality were listed above in Sections 4.3.2 and 4.3.2. and in applicable NSF Testing Plans.*
- *Description of data recording protocol for equipment operation, feedwater quality parameters, and treated water quality parameters.*
- *Description of the confidence interval calculation procedure for selected water quality parameters.*
- *Detailed outline of the verification testing schedule.*

5.0 FIELD OPERATIONS PROCEDURES

5.1 Equipment Operations and Design

The NSF Verification Testing Plan specifies procedures that shall be used to ensure the accurate documentation of both equipment performance and treated water quality. Careful adherence to these procedures will result in definition of verifiable performance of equipment. (Note that this protocol may be associated with a number of different NSF Equipment Verification Testing Plans for different types of process equipment capable of achieving removal of DBP precursors).

Design aspects of water treatment process equipment often provide a basis for approval by state regulatory officials and can be used to ascertain if process equipment intended for larger or smaller flow involves the same operating parameters that were relevant to the verification testing. Specific design aspects to be included in the FOD are provided in detail, in the Field Testing Organization Responsibilities section below.

Initial operations of the precursor removal equipment will allow equipment Manufacturers to refine their operating procedures and to make operational adjustments as needed to successfully treat the feedwater. Information generated through this period of operation may be used to revise the FOD, if necessary. A failure at this point in the verification testing could indicate a lack of capability of the process equipment and the verification testing might be canceled.

5.2 Communications, Documentation, Logistics, and Equipment

The successful implementation of the verification testing will require detailed coordination and constant communication between all verification testing participants.

All field activities shall be thoroughly documented. Field documentation will include field logbooks, photographs, field data sheets, and chain-of-custody forms. The qualified Field Testing Organization shall be responsible for maintaining all field documentation. Field notes shall be kept in a bound logbook. Each page shall be sequentially numbered and labeled with the project name and number. Field logbooks shall be used to record all water treatment equipment operating data. Completed pages shall be signed and dated by the individual responsible for the entries. Errors shall have one line drawn through them and this line shall be initialed and dated.

All photographs shall be logged in the field logbook. These entries shall include the time, date, direction, subject of the photograph, and the identity of the photographer. Any deviations from the approved final FOD shall be thoroughly documented in the field logbook at the time of inspection and in the verification report.

Original field sheets and chain-of-custody forms shall accompany all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided at the time of the QA/QC inspection and included in the verification report.

5.3 Equipment Operation and Water Quality Sampling for Verification Testing

All field activities shall conform with requirements provided in the FOD that was developed and NSF-approved for the verification testing being conducted. If unanticipated or unusual situations are encountered that may alter the plans for equipment operation, water quality sampling, or data quality, the situation must be discussed with the NSF technical lead. Any deviations from the approved final FOD shall be thoroughly documented.

During routine operation of water treatment equipment, the total number of hours during which the equipment is operated each day shall be documented. In addition, the number of hours each day during which the operator was working at the treatment plant performing tasks related to water treatment and the operation of the treatment equipment shall be documented. Furthermore, the tasks performed during equipment operation shall be described by the Field Testing Organization, the Water System or the Plant Operator.

Content of FOD Regarding Field Operations Procedures:

The FOD shall include the following elements:

- *A table summary of the proposed time schedule for operating and testing,*
- *Field operating procedures for the equipment and performance testing, based upon the NSF Equipment Verification Testing Plan with listing of operating parameters, ranges for feedwater quality, and the sampling and analysis strategy.*

Manufacturer Responsibilities:

- *Provision of all equipment needed for field work associated with this verification testing;*
- *Provision of a complete list of all equipment to be used in the verification testing. A table format is suggested;*
- *Provision of field operating procedures.*

6.0 QUALITY ASSURANCE PROJECT PLAN (QAPP)

The QAPP for this verification testing specifies procedures that shall be used to ensure data quality and integrity. Careful adherence to these procedures will ensure that data generated from the verification testing will provide sound analytical results that can serve as the basis for performance verification.

6.1 Purpose and Scope

The purpose of this section is to outline steps that shall be taken by operators of the equipment and by the analytical laboratory to ensure that data resulting from this verification testing is of known quality and that a sufficient number of critical measurements are taken.

6.2 Quality Assurance Responsibilities

A number of individuals may be responsible for monitoring equipment operating parameters and for sampling and analysis QA/QC throughout the verification testing. Primary responsibility for ensuring that both equipment operation and sampling and analysis activities comply with the QA/QC requirements of the FOD (Section 6) shall rest with the Field Testing Organization.

QA/QC activities for the analytical laboratory that analyzes samples sent off-site shall be the responsibility of that analytical laboratory's supervisor. If problems arise or any data appear unusual, they shall be thoroughly documented and corrective actions shall be implemented as specified in this section. The QA/QC measurements made by the off-site analytical laboratory are dependent on the analytical methods being used.

6.3 Data Quality Indicators

The data obtained during the verification testing must be of sound quality for conclusions to be drawn on the equipment. For all measurement and monitoring activities conducted for equipment verification, the NSF and EPA require that data quality parameters be established based on the proposed end uses of the data. Data quality parameters include four indicators of data quality: representativeness, accuracy, precision, and statistical uncertainty.

Treatment results generated by the equipment and by the laboratory analyses must be verifiable for the purposes of this program to be fulfilled. High quality, well documented analytical

laboratory results are essential for meeting the purpose and objectives of this verification testing. Therefore, the following indicators of data quality shall be closely evaluated to determine the performance of the equipment when measured against data generated by the analytical laboratory.

6.3.1 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter represented by the data. In this verification testing, representativeness will be ensured by maintaining consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping, and by executing random DBP spiking procedures. Representativeness also will be ensured by using each method at its optimum capability to provide results that represent the most accurate and precise measurement it is capable of achieving. For equipment operating data, representativeness entails collecting a sufficient quantity of data during operation to be able to detect a change in operations.

6.3.2 Accuracy

For water quality analyses, accuracy refers to the difference between an experimentally determined sample result and the accepted reference value for the sample. Analytical accuracy is a measure of analytical bias due to systematic errors. Loss of accuracy can be caused by such processes as errors in standards preparation, equipment calibrations, loss of target analyte in the extraction process, interferences, and systematic or carryover contamination from one sample to the next.

In this verification testing, the FTO will be responsible for maintaining consistent sample collection procedures, including sample locations, timing of sample collection, sampling procedures, sample preservation, sample packaging, and sample shipping to maintain a high level of accuracy in system monitoring. The FTO shall discuss the applicable ways of determining the accuracy of the chemical and microbiological samples and analytical techniques in the FOD.

For equipment operating parameters, accuracy refers to the difference between the reported operating condition and the actual operating condition. For equipment operating data, maintaining a high level of accuracy will require collecting a sufficient quantity of data during operation to be able to detect a change in operations. For water flow, accuracy may be the difference between the reported flow indicated by a flow meter and the flow as actually measured on the basis of known volumes of water and carefully defined times (bucket and stopwatch technique) as practiced in hydraulics laboratories or water meter calibration shops. For mixing equipment, accuracy is the difference between an electronic readout for equipment RPMs and the actual measurement based on counted revolutions and measured time. Accuracy of head loss measurement can be determined by using measuring tapes to check the calibration of piezometers for gravity filters or by checking the calibration of pressure gauges for pressure filters. Meters and gauges must be checked periodically for

accuracy, and when proven to be dependable over time, the time interval between accuracy checks can be increased. In the FOD, the FTO shall discuss the applicable ways of determining the accuracy of the operational conditions and procedures.

From an analytical perspective, accuracy represents the deviation of the analytical value from the known value. Since true values are never known in the field, accuracy measurements are made on analysis of OC samples analyzed with field samples. QC samples for analysis shall be prepared with laboratory control samples, matrix spikes and spike duplicates. It is recommended for verification testing that the FOD include laboratory performance of one matrix spike for determination of sample recoveries. Recoveries for spiked samples are calculated in the following manner:

% Recovery = 100 x (SSR-SR)/SA

where: SSR = spiked sample results
SR = sample result
SA = spike amount added

Recoveries for laboratory control samples are calculated as follows:

% Recovery = 100 x (found concentration)/(true concentration)

For acceptable analytical accuracy under the verification testing program, the recoveries reported during analysis of the verification testing samples must be within control limits, where control limits are defined as the mean recovery plus or minus three times the standard deviation.

6.3.3 Precision

Precision refers to the degree of mutual agreement among individual measurements and provides an estimate of random error. Analytical precision is a measure of how far an individual measurement may be from the mean of replicate measurements. The standard deviation and the relative standard deviation recorded from sample analyses may be reported as a means to quantify sample precision. The percent relative standard deviation may be calculated in the following manner:

$$\% \text{ Relative Standard Deviation} = \frac{S(100)}{X_{average}}$$

where: S = standard deviation
$X_{average}$ = the arithmetic mean of the recovery values.

Standard Deviation is calculated as follows:

$$\text{Standard Deviation} = \sqrt{\frac{(X_i - X)^2}{n-1}}$$

Where: X_i = the individual recovery values
X = the arithmetic mean of then recovery values
n = the number of determinations.

For acceptable analytical precision under the verification testing program, the percent relative standard deviation for drinking water samples must be less than 30%.

6.3.4 Statistical Uncertainty

Statistical uncertainty of the water quality parameters analyzed shall be evaluated through calculation of the 95% confidence interval around the sample mean. Description of the confidence interval calculation is provided in Section 4.6 - Recording Statistical Uncertainty.

6.4 Water Quality and Operational Control Checks

This section describes the QC requirements that apply to both the treatment equipment and the on-site measurement of water quality parameters. It also contains a discussion of the corrective action to be taken if the QC parameters fall outside of the evaluation criteria.

The quality control checks provide a means of measuring the quality of data produced. The Manufacturer may not need to use all the ones identified in this section. The selection of the appropriate quality control checks depends on the equipment, the experimental design and the performance goals. The selection of quality control checks will be based on discussions among the Manufacturer and the NSF.

6.4.1 Quality Control for Equipment Operation

This section will explain the methods to be used to check on the accuracy of equipment operating parameters and the frequency with which these quality control checks will be made. If the quality of the equipment operating data can not be verified, then the water quality analytical results may be of no value. Because water can not be treated if equipment is not operating, obtaining valid equipment operating data is a prime concern for verification testing.

An example of the need for QC for equipment operations is an incident of state rejection of test data because the treatment equipment had no flow meter to use for determining engineering and operating parameters related to flow.

6.4.2 Water Quality Data

After treatment equipment is being operated and water is being treated, the results of the treatment are interpreted in terms of water quality. Therefore the quality of water sample analytical results is just as important as the quality of the equipment operating data. Most QA plans emphasize analytical QA. The important aspects of sampling and analytical QA are given below:

6.4.2.1 Triplicate Analysis of Selected Water Quality Parameters. Triplicate samples shall be analyzed for selected water quality parameters at specified intervals in order to determine the precision of analysis. The procedure for determining samples to be analyzed in triplicate shall be provided in each Verification Testing Plan with the required frequency of analysis and the approximate number. The triplicate analysis shall be performed according to the requirements for calculation of 95% confidence intervals, as presented in Section 4.6.

6.4.2.2 Method Blanks. Method blanks are used for selected water quality parameters to evaluate analytical method-induced contamination, which may cause false positive results.

6.4.2.3 Spiked Samples. The use of spiked samples will depend on the testing program, and the contaminants to be removed. If spiked samples are to be used specify the procedure, frequency, acceptance criteria, and actions if criteria are not met.

6.4.2.4 Travel Blanks. Travel blanks for selected water quality parameters shall be provided to the analytical laboratory to evaluate travel-related contamination.

6.4.2.5 Performance Evaluation Samples for On-Site Water Quality Testing. Performance evaluation (PE) samples are samples whose composition is unknown to the analyst that are used to evaluate analytical performance. Analysis of PE samples shall be conducted for selected water quality parameters before pilot testing is initiated by submission of samples to the analytical laboratory. The control limits for the PE samples will be used to evaluate the equipment testing organization's and analytical laboratory's method performance. One kind of PE sample that would be used for on-site QA in most studies done under this protocol would be a turbidity PE sample.

PE samples come with statistics about each sample which have been derived from the analysis of the sample by a number of laboratories using EPA-approved methods. These statistics include a true value of the PE sample, a mean of the laboratory results obtained from the analysis of the PE sample, and an acceptance range for sample values. The analytical laboratory is expected to provide results from the analysis of the PE samples that meet the performance objectives of the verification testing.

6.5 Data Reduction, Validation, and Reporting

To maintain good data quality, specific procedures shall be followed during data reduction, validation, and reporting. These procedures are detailed below.

6.5.1 Data Reduction

Data reduction refers to the process of converting the raw results from the equipment into concentration or other data in a form to be used in the comparison. The procedures to be used will be equipment dependent. The purpose of this step is to provide data which will be used to verify the statement of performance capabilities. These data shall be obtained from logbooks, instrument outputs, and computer outputs as appropriate.

6.5.2 Data Validation

The operator shall verify the completeness of the appropriate data forms and the completeness and correctness of data acquisition and reduction. The field team supervisor or another technical person shall review calculations and inspect laboratory logbooks and data sheets to verify accuracy, completeness. Calibration and QC data will be examined by the individual operators and the laboratory supervisor. Laboratory and project managers shall verify that all instrument systems are in control and that QA objectives for accuracy, completeness, and method detection limits have been met.

Analytical outlier data are defined as those QC data lying outside a specific QC objective window for precision and accuracy for a given analytical method. Should QC data be outside of control limits, the analytical laboratory or field team supervisor will investigate the cause of the problem. If the problem involves an analytical problem, the sample will be reanalyzed. If the problem can be attributed to the sample matrix, the result will be flagged with a data qualifier. This data qualifier will be included and explained in the final analytical report.

6.5.3 Data Reporting

The Field Testing Organization shall provide to the NSF a list of all water quality and equipment operation data to be reported. At a minimum, the data tabulation shall list the results for feedwater and treated water quality analyses and equipment operating data. All QC information such as calibrations, blanks and reference samples are to be included in an appendix to the report submitted to NSF. All raw analytical data shall also be reported in an appendix. All data shall be reported in hardcopy and electronically in a common spreadsheet or database format.

6.6 System Inspections

On-site system inspections for sampling activities, field operations, and laboratories may be conducted as specified by the NSF Equipment Verification Testing Plan. These inspections will

be performed by the verification entity to determine if the NSF Equipment Verification Testing Plan is being implemented as intended. At a minimum, NSF shall conduct one audit of the sampling activities, field operations program and laboratories during the Verification Testing Study. The number of audits performed during a study shall be specified by the pertinent Equipment Verification Testing Plan. Separate inspection reports will be completed after the audits and provided to the participating parties.

6.7 Reports

6.7.1 Status Reports

The Field Testing Organization shall prepare periodic reports for distribution to pertinent parties, e.g., manufacturer, EPA, the community. These reports shall discuss project progress, problems and associated corrective actions, and future scheduled activities associated with the verification testing. Each report shall include an executive summary at the beginning of the report to introduce the salient issues of the testing period. When problems occur, the Manufacturer and Field Testing Organization project managers shall discuss them, and estimate the type and degree of impact, and describe the corrective actions taken to mitigate the impact and to prevent a recurrence of the problems. The frequency, format, and content of these reports shall be outlined in the FOD.

6.7.2 Audit Reports

Any QA inspections that take place in the field or at the analytical laboratory while the verification testing is being conducted shall be formally reported by the Field Testing Organization verification entity and manufacturer.

6.8 Corrective Action

Each FOD must incorporate a corrective action plan. This plan must include the predetermined acceptance limits, the corrective action to be initiated whenever such acceptance criteria are not met, and the names of the individuals responsible for implementation.

Routine corrective action may result from common monitoring activities, such as:

- Performance evaluation audits
- Technical systems audits

Content of Field Operations Document Regarding Quality Assurance Project Plan:

The FOD shall include the following elements:

- *Description of methodology for measurement of accuracy.*
- *Description of methodology for measurement of precision.*

- *Description of the methodology for use of blanks, the materials used, the frequency, the criteria for acceptable method blanks and the actions if criteria are not met.*
- *Description of any specific procedures appropriate to the analysis of the PE samples.*
- *Outline of the procedure for determining samples to be analyzed in triplicate, the frequency and approximate number.*
- *Description of the procedures used to assure that the data are correct.*
- *Listing of equations used for any necessary data quality indicator calculations. These include: precision, standard deviation, 95% confidence interval calculation; accuracy, and representativeness.*
- *Outline of the frequency, format, and content of reports in the FOD.*
- *Development of a corrective action plan in the FOD.*

Field Testing Organization Responsibilities:

- *Provision of all QC information such as calibrations, blanks and reference samples in an appendix. All raw analytical data shall also be reported in an appendix.*
- *Provision of all data in hardcopy and electronic form in a common spreadsheet or database format.*

7.0 DATA MANAGEMENT AND ANALYSIS, AND REPORTING

7.1 Data Management and Analysis

A variety of data will be generated during a verification testing. Each piece of data or information identified for collection in the NSF Equipment Verification Testing Plan will need to be provided in the report. The data management section of the FOD shall describe what types of data and information needs to be collected and managed, and shall also describe how the data will be reported to the NSF for evaluation.

Laboratory Analyses: The raw data and the validated data must be reported. These data shall be provided in hard copy and in electronic format. As with the data generated by the innovative equipment, the electronic copy of the laboratory data shall be provided in a spreadsheet. In addition to the sample results, all QA/QC summary forms must be provided.

Other items that must be provided include:

- field notebooks;
- photographs, slides and videotapes (copies);
- results from the use of other field analytical methods.

7.2 Report of Equipment Testing

The Field Testing Organization shall prepare a draft report describing the verification testing that was carried out and the results of that testing. This report shall include the following topics:

- Introduction
- Executive Summary
- Description and Identification of Product Tested
- Procedures and Methods Used in Testing
- Results and Discussion
- Conclusions and Recommendations
- References
- Appendices
- Manufacturer FOD
- QA/AC Results

Content of FOD Regarding Data Management and Analysis, and Reporting:

The FOD shall include the following:

- *Description of what types of data and information needs to be collected and managed.*
- *Description of how the data will be reported.*

8.0 SAFETY MEASURES

The safety procedures shall address safety considerations, including the following as applicable:

- storage, handling, and disposal of hazardous chemicals including acids, caustic and oxidizing agents.
- conformance with electrical code
- biohazards
- ventilation of equipment or of trailers or buildings housing equipment, if gases generated by the equipment could present a safety hazard (one example is ozone).

Content of FOD Regarding Safety:

The FOD shall address safety considerations that are appropriate for the equipment being tested and for the chemicals employed in the verification testing.

CHAPTER 2

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN MEMBRANE PROCESSES FOR THE REMOVAL OF PRECURSORS TO DISINFECTION BY-PRODUCTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is an NSF Equipment Verification Testing Plan for evaluation of water treatment equipment utilizing membrane processes. This Testing Plan is to be used as a guide in the development of a Field Operations Document for testing of membrane process equipment to achieve removal of precursors to disinfection by-products (DBPs). Refer to the "Protocol For Equipment Verification Testing Removal of Precursors to Disinfection By-Products" for further information. It should be noted that this Equipment Verification Plan is only applicable to pressure-driven membrane processes. This NSF Equipment Verification Testing Plan is applicable to any pressure-driven membrane process used to achieve removal of precursors to DBPs.

Furthermore, this testing plan is applicable to any membrane configuration and geometries as long as it is adequately described by the Manufacturer. Various membrane configurations are currently employed for water treatment applications including:

- spiral-wound (SW)
- hollow-fiber (HF)
- tubular
- cassette
- cartridge
- flat sheet

In order to participate in the equipment verification process for membrane processes, the equipment Manufacturer and their designated Field Testing Organization shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of Field Operations Document (FOD). The FOD should generally follow those Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing Program is to achieve removal of DBP precursors present in water supplies such that product waters are of acceptable water quality. The driving force for the goal of precursor removal is to achieve compliance with any future Disinfectant /Disinfection By-Product (D/DBP) regulations under the Safe Drinking Water Act. The experimental design of the FOD shall therefore be developed so the relevant questions about water treatment equipment capabilities can be answered. Each FOD shall include all of the included tasks, Tasks 1 to 5.

2.0 INTRODUCTION

Pressure-driven membrane processes are currently in use for a broad number of water treatment applications ranging from removal of particulate matter to removal of natural organic matter contributing to disinfection by-product formation and microbial contaminants such as *Giardia* and *Cryptosporidium*. Typically, higher pressure membrane applications such as nanofiltration (NF) and reverse osmosis (RO) are predominantly employed to achieve removal of inorganic constituents, total dissolved solids, total organic carbon (TOC), and other inorganic constituents such as salt species. Pretreatment processes ahead of NF or RO systems are generally required to remove particulate material and to ensure provision of a high quality water to the membrane systems. Typically, low pressure membrane processes, such as microfiltration (MF) and ultrafiltration (UF) are employed to provide a physical barrier for removal of microbial and particulate contaminants from source waters. However, these low pressure membrane processes have also been shown to be effective for removal of TOC and precursors to DBPs when used in conjunction with pretreatment processes.

3.0 GENERAL APPROACH

This NSF Equipment Verification Testing Plan is broken down into 5 tasks, as shown in the Experimental Matrix, Table 1. As noted above, these Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified by NSF. The Manufacturer's designated Field Testing Organization shall provide full detail of the procedures to be followed in each Task in the FOD. The Field Testing Organization shall specify the operational conditions to be verified during Verification Testing. All permeate flux values shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 68 °F or liters per square meter per hour (L/(m^2-hr) at 20 °C.

It should be noted that NF and RO membranes cannot be applied to surface waters without pretreatment of the feedwater to the membrane system. For surface water applications, proper pretreatment must be applied as specified by the Manufacturer. In the design of the FOD, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application before the NF and RO membrane processes. The recommended pretreatment process(es) shall then be employed for feedwater pretreatment during implementation of the Equipment Verification Testing Program.

The verification testing shall be performed in one two-month testing period (not including time for system shakedown and mobilization). At a minimum, one, two-month period of verification testing shall be conducted.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the required and optional tasks to be included in the membrane verification testing program.

4.1 Task 1: Membrane Flux and Operation

The objective of this task is to evaluate membrane operation. Membrane productivity, rate of flux decline, and rejection capabilities will be evaluated in relation to feedwater quality and changes in quality resulting from seasonal or climatic changes. The impact of scale formation on membrane flux may also be evaluated via addition of different pretreatment chemicals.

4.2 Task 2: Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after flux decline has occurred. The objective of this task is to evaluate the efficiency of the membrane cleaning procedures recommended by the Manufacturer. The fraction of specific flux which is restored following a chemical cleaning will be determined.

4.3 Task 3: Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the membrane system. Multiple water quality parameters will be monitored during the two-month testing period. The required water quality parameters, shall include TOC, UV absorbance (at 254 nm wavelength), DBP formation potential (specific DBPs to be identified by Manufacturer), total dissolved solids, conductivity, alkalinity, calcium hardness, ortho-phosphate, sulfate, chloride, bromide, silica (total & dissolved) Fe, Mn, and turbidity. Other water quality parameters will be optional, such as color, heterotrophic plate count (HPC), bacteria, and individual metal ion concentrations. Water quality produced will be evaluated in relation to feedwater quality and operational conditions. Post-treatment capabilities of the packaged equipment shall also be evaluated for removal of carbon dioxide and hydrogen sulfide from the permeate water (if present).

4.4 Task 4: Data Management

The objective of this task is to establish effective field protocol for data management at the field operations site and for data transmission between the Field Testing Organization and the NSF.

4.5 Task 5: QA/QC

An important aspect of verification testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during membrane equipment verification testing.

5.0 TESTING PERIODS

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 5) are designed to be completed over one (1) two-month period, not including mobilization, shakedown and start-up. Membrane testing conducted beyond the required two months of testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During testing periods, Tasks 2 and 3 (evaluation of cleaning efficiency and finished water quality) can be performed concurrent with Task 1, the flux and operation testing procedures.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's claims, such as in the treatment of surface water where additional testing during each season may assist in verifying a claim. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's claims. For example, climatic changes between rainy and dry seasons may produce substantial variability in feedwater turbidity for surface water sources. Cold weather operations will be an important component of seasonal water quality testing because of the impact of cold temperatures (1°C to 5°C) on water viscosity and diffusional processes. In particular, for membrane process treatment equipment, factors that can influence treatment performance include:

- high concentration of natural organic matter (measured as TOC), which may be higher in some waters during different seasonal periods;
- high turbidity, often occurring in spring as a result of high runoff resulting from heavy rains or snowmelt;
- feedwaters with high seasonal hardness and total dissolved solids (TDS) concentration. These conditions may promote precipitation of inorganic materials in the membrane.
- cold water, encountered in winter or at high altitude locations;
- feedwaters that may exhibit algal blooms on a seasonal basis.

It is highly unlikely that all of the above problems would occur in a water source during a single two-month period, and this results in the recommendation for additional two-month testing periods. Although one testing period satisfies the minimum requirement of the Environmental Technology Verification Program (ETVP), manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined by the manufacturer. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of two-months. The purpose of the two-month test period is to demonstrate the ability of the equipment to meet the water quality goals specified by the Manufacturer and to assess the product water recovery and the rate of flux decline observed during the period of operation.

6.0 DEFINITION OF OPERATIONAL PARAMETERS

6.1 Permeate: Water produced by the NF or RO membrane filtration process.

6.2 Feedwater: Water introduced to the membrane module.

6.3 Concentrate: Concentrated solution of membrane-rejected materials retained on the feedwater side of the membrane during cross-flow membrane filtration. In a multiple-stage membrane configuration, this concentrated stream of rejected materials is passed to the subsequent stage of the membrane process array for further concentration.

6.4 Permeate Flux: The average permeate flux is the flow of permeate water divided by the surface area of the membrane. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

where: J_t = permeate flux at time t (gfd, L/(h-m^2))
Q_p = permeate flow (gpd, L/h)
S = membrane surface area (ft^2, m^2)

It should be noted that only gfd and L/(h-m^2) shall only be used as units of flux.

6.5 Specific Flux: The term specific flux is used to refer to permeate flux that has been normalized for the transmembrane pressure. The equation used for calculation of specific flux is given as follows:

$$J_{tm} = \frac{J_t}{P_{tm} - \Delta\pi}$$

where J_{tm} = specific flux at time t (gfd/psi, L/(h-m^2)/bar)
J_t = permeate flux at time t (gfd, L/(h-m^2))
P_{tm} = transmembrane pressure (psi, bar)
$\Delta\pi$ = osmotic pressure (psi, bar)

Specific flux results shall always be reported with indication of the time interval after initiation of the experimental test run.

6.6 Membrane Fouling: A reduction in permeate flux that can be restored by mechanical or chemical means is termed ”reversible” fouling. In contrast, “irreversible fouling” is defined as a permanent loss in permeate flux capacity that cannot be restored.

6.7 Transmembrane Pressure: The average transmembrane pressure is calculated:

$$P_{tm} = \left[\frac{(P_i + P_o)}{2} - \Delta\pi \right] - P_p$$

where P_{tm} = transmembrane pressure (psi, bar)
P_i = pressure at the inlet of the membrane module (psi, bar)
P_o = pressure at the outlet of the membrane module (psi, bar)
$\Delta \pi$ = osmotic pressure (psi, bar)
P_p = permeate pressure (psi, bar)

6.8 Temperature Adjustment for Flux Calculation: Temperature corrections to 20°C for transmembrane flux shall be made to correct for the variation of water viscosity with temperature (Streeter and Wiley, 1985). A specific, empirically-derived equation developed by the membrane manufacturer may be used to provide temperature corrections for specific flux calculations, or the following equation by Streeter and Wiley (1985) may be employed:

$$J_{tm}(\text{at } 20^{o}\text{C}) = \frac{Q_p \times e^{-0.024 \times (\text{TC} - 20^{0}\text{C})}}{S}$$

where J_{tm} = instantaneous flux (gfd, L/(h-m^2))
Q_p = permeate flow (gpd, L/h)
T = temperature, (°C)
S = membrane surface area (ft^2, m^2)

6.9 Feedwater Recovery: The total recovery of permeate from feedwater is given as the ratio of total permeate flow to feedwater flow:

$$\% \text{ System Recovery} = 100\left[\frac{Q_p}{Q_f} \right]$$

where Q_p = permeate flow (gpd, L/h)
Q_f = feed flow to the membrane (gpd, L/h)

6.10 Membrane Process Recovery: The recovery of permeate from total recirculation influent water is given as the ratio of permeate flow to the sum of feedwater flow and recycle flow:

$$\% \text{ Element Recovery} = 100\left[\frac{Q_p}{Q_f + Q_r} \right]$$

where Q_p = permeate flow (gpd, L/h)
Q_f = feed flow to the membrane (gpd, L/h)
Q_r = recycle flow (gpd, L/h)

6.11 **Foulants:** Plugging or deposition or bonding of dissolved/suspended matter on the membrane surface. It typically occurs at the front end of each pressure vessel when the feed enters the membrane.

6.12 **Scaling**: The precipitation of sparingly soluble salts within the feed side of the membrane. It typically occurs at the end of each pressure vessel where concentration is greatest.

7.0 TASK 1: MEMBRANE FLUX AND OPERATION

7.1 Introduction

Membrane operation will be evaluated in this task, with quantification of membrane flux decline rates and permeate water recoveries. The rates of flux decline will be used to demonstrate membrane performance at the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the Field Testing Organization in terms of a temperature-corrected flux value (e.g., gfd at 68 °F or L/(m^2-hr) at 20 °C) before the initiation of the Verification Testing Program.

Rate of flux decline is a function of water quality and operational strategy. Many additional factors may influence specific flux decline with high-pressure membranes such as NF & RO including membrane compaction, membrane ripening, inorganic scaling, particulate or organic fouling, biofouling, and other factors. In this task, specific flux decline and water quality shall be monitored to evaluate operational trends and membrane rejection capabilities. Flowrate, pressure, and temperature data shall be collected to quantify the rate of specific flux decline. A lower rate of specific flux decline implies that a longer operational run will be achieved by the membrane system.

Some manufacturers may wish to employ a low pressure membrane system preceded by an organics removal pretreatment process (such as pretreatment addition of a coagulant or adsorbent prior to membrane filtration) in order to achieve removal of precursors to DBPs. Any pretreatment included in the membrane treatment system that is designed for removal of precursors to DBPs shall be considered an integral part of the packaged membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes.

Before the initiation of verification testing, the Manufacturers shall make known the limitations of the equipment and any existing equipment incompatibilities with treatment processes or chemical additions. To this end, a listing shall be provided by the Manufacturer describing the potentially incompatible treatment processes or chemical additions (i.e., oxidants, coagulants,

anti-scalants) that would adversely impact the equipment materials or the treatment process. In addition, the Field Testing Organization shall report any incompatibilities between equipment and treatment processes or chemical additions that are observed during the course of the Verification Testing Program.

7.2 Experimental Objectives

The objectives of this task are to demonstrate 1) the appropriate operational conditions for the membrane equipment; 2) the permeate water recovery achieved by the membrane equipment; and 3) the rate of flux decline observed over extended membrane filtration operation. Raw water quality shall be monitored (Task 3) during the two-month testing period in order to track any variations in water quality that could impact fouling rates. The potential for significant variation in raw water quality applies primarily to surface waters.

It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the Field Testing Organization, as pertains to permeate flux and transmembrane pressure. Verification of membrane operation shall also apply to operating conditions that are considered less stringent than those conditions tested; examples would include lower permeate fluxes and higher cross-flow velocities.

7.3 Work Plan

Determination of optimal membrane operating conditions for a particular water can typically require as long as one year of operation. For this task the Field Testing Organization shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the membrane treatment system. The Field Testing Organization shall also specify the membrane run termination criteria for the particular membrane equipment. For example, the termination criteria may be defined as an 20% decline in specific flux, or increase in transmembrane pressure to a specific value. In this task, each set of operating conditions shall be maintained for a two-month testing period (continuous 24-hour operation). Because only one testing period shall be required (two-months) in this Verification Testing Plan, the Field Testing Organization shall specify the primary permeate flux at which the equipment is to be verified.

After set-up and shakedown of membrane equipment, membrane operation should be established at the flux condition to be verified. The membrane system shall be operated as shown schematically in Figure 1 for a minimum of two months. If substantial specific flux decline occurs under this specified flux condition before the two-month operating period is complete, adjustments to the operational strategy shall be made (such as a decrease in flux or recovery). Decisions on adjustments shall be made based upon the Manufacturer's experience and consultation with the NSF-qualified Field Testing Organization conducting the study. At a minimum, the membrane shall be chemically cleaned according to Manufacturer's specifications at the conclusion of the two-month period. At this time, the cleaning efficiency shall be determined per Task 2.

This NSF Membrane Verification Testing Plan has been written with the aim to balance the costs of verification with the benefits of testing membrane filtration over a wide range of operating conditions. Given that it may take one month longer to observe significant flux decline in a high-pressure membrane system, examination under a wide range of operating conditions would be prohibitively expensive for the membrane Manufacturer. Therefore, this Verification Testing Plan requires that one set of operating conditions be tested for the one two-month period. It shall be furthermore understood that beyond the single set of verification operating conditions, membrane operation that occurs at a lower flux, a lower recovery, or a higher cross-flow velocity shall also constitute a verifiable condition.

In order to establish appropriate conditions of flux, recovery, backwash frequency and duration the manufacturer may have some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the verification testing. The need of pre-test optimization should be carefully addressed with NSF, the Field Testing Organization and the Manufacturer early in the process.

Testing of additional operational conditions may be included in the verification testing program at the discretion of the Manufacturer and their designated Field Testing Organization. Testing of alternate operational conditions shall be performed by including additional two-month testing periods. Operation of the membrane equipment during the optional testing periods shall be supervised by the Field Testing Organization or by a separate entity, as determined by previous agreement between the Manufacturer and the Field Testing Organization.

Additional months of testing may also be included in the Verification Testing Plan in order to demonstrate membrane performance under different feedwater quality conditions. For membrane filtration, extremes of feedwater quality (e.g., low temperature, high TOC concentration, high TDS, high turbidity) are the conditions under which membranes are most prone to rapid flux decline and to failure. The Field Testing Organization shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional two-month testing period, as required above for each additional set of operating conditions.

The testing runs conducted under this task shall be performed in conjunction with Tasks 2 and 3. With the exception of the additional testing periods conducted at the Field Testing Organization's discretion, no additional membrane test runs are required for performance of Tasks 2 and 3.

7.4 Analytical Schedule

7.4.1 Operational Data Collection

Measurement of membrane feedwater flow and permeate flow (recycle flow where applicable) and system pressures shall be collected at a minimum of 2 times per day. Temperatures (feedwater, permeate, recirculation water, concentrate) shall be collected at a minimum once daily. Table 2 presents the operational data collection schedule. Temperature measurements shall be made in order to provide data for correction of transmembrane flux.

In an attempt to calculate costs for operation of membrane equipment, power costs for operation of the membrane equipment shall also be closely monitored and recorded by the Field Testing Organization during the two-month testing period. Power usage shall be quantified by the following measurements: pumping requirements, size of pumps, nameplate voltage, current draw, power factor. Chemical usage shall be quantified by recording day tank concentration and daily volume consumption. No additional operational data shall be required by Tasks 2 through 4 unless specifically stated.

7.4.2 Feedwater Quality Limitations

The characteristics of feedwaters used during the two-month testing period (and any additional testing periods) shall be explicitly stated in reporting the membrane flux and recovery data. Accurate reporting of such feedwater characteristics as temperature, TOC concentration, UV_{254} absorbance, TDS, conductivity, alkalinity, calcium hardness, ortho-phosphate, sulfate, chloride, bromide, iron, manganese, silica, turbidity, and pH is critical for the Verification Testing Program, as these parameters may substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions.

7.4.3 Waste Stream Water Quality

The waste streams from the treatment process equipment shall be characterized by measurement of the following water quality parameters: pH, TDS, TOC, coliform bacteria, as indicated in Table 3. Quantification shall also be provided of the rates of consumption of chemicals and rates of waste production. The specific waste stream flows from routine cleaning, chemical cleaning and other cleaning processes shall be quantified individually.

7.5 Evaluation Criteria and Minimum Reporting Requirements

- Rate of specific flux decline
- ⇒ Plot graph of specific flux normalized to 20°C over time for each 60 day period of operation
- Cleaning efficiency

⇒ Provide table of intervals between chemical cleaning episodes and efficiency of cleaning following the two-month period of operation

- Waste Stream Water Quality

⇒ Provide table of waste stream concentrations of any measured water quality parameters for each 60 day period of operation

- Report of Equipment Incompatibilities

⇒ Provide report of any observed incompatibilities between equipment and treatment processes or chemical additions.

8.0 TASK 2: CLEANING EFFICIENCY

8.1 Introduction

Following the test runs of Task 1, the membrane equipment may require chemical cleaning to restore membrane productivity. At a minimum, one cleaning shall be performed at the conclusion of the two-month period of required testing. In the case where the membrane does not fully reach the operational criteria for termination as specified by the Manufacturer and their designated Field Testing Organization in Task 1, chemical cleaning shall be performed after the 60 days of operation, with a record made of the operational conditions before and after cleaning.

8.2 Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning for restoring specific flux of the membrane systems. The intent of this task is to confirm that standard Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity and do not degrade the membrane in terms of organics rejection capabilities for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the recommendations of the Manufacturer; this task is considered a "proof of concept" effort, not an optimization effort. It should be noted that cleaning solution selection is typically feedwater quality specific. The testing plan should permit evaluation of cleaning solutions that are considered optimal for water being treated. If the Manufacturer determines that a pre-selected cleaning formulation is not effective, the testing plan should allow the Manufacturer to modify it.

8.3 Work Plan

The membrane systems may experience specific flux decline during the membrane test runs conducted for Task 1. At the conclusion of the two-month testing period, these membranes shall be utilized for the cleaning assessments herein. No additional experiments shall be required to produce specific flux decline such that chemical cleaning evaluations be performed. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the initial conditions of specific flux recovery and organics rejection capabilities shall be tested.

The Manufacturer and their designated Field Testing Organization shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- quantities and costs of cleaning chemicals
- hydraulic conditions of cleaning
- duration of each cleaning step
- initial and final temperatures of chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed
- recommended methods and considerations for disposal of residual cleaning waste

In addition, detailed procedures describing the methods for pH neutralization of the acid or alkaline cleaning solutions should be provided along with information on the proper disposal method for regulated chemicals. A description of all cleaning equipment and its operation shall be included in the FOD prepared by the Manufacturer designated Field Testing Organization.

8.4 Analytical Schedule

8.4.1 Sampling

The pH, conductivity, TDS, and turbidity of each cleaning solution shall be measured and recorded during various periods of the chemical cleaning procedure. In addition, in the case that the cleaning solution employs an oxidant, such as chlorine, the concentration of the oxidant both before and at the end of the cleaning should be measured. Notes recording the visual observations (color, degree of suspended matter present) shall also be provided by the Field Testing Organization. No other water quality sampling shall be required.

8.4.2 Operational Data Collection

Flow, pressure, recovery, and temperature data shall be collected during the cleaning procedure if possible and shall be recorded immediately preceding system shutdown. At the conclusion of each chemical cleaning event and immediately upon return to membrane operation, the initial condition of transmembrane pressure, recovery, and temperature shall be recorded and the specific flux calculated.

8.5 Evaluation Criteria and Minimum Reporting Requirements

The efficacy of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficacy achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible loss of specific flux and projections for usable membrane life. Analysis of feedwater and permeate water quality in subsequent runs shall also be used to evaluate any loss in membrane rejection capabilities caused by chemical cleaning.

Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1) The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (Js_f) and the initial specific flux (Js_i) measured for the subsequent filtration run:

$$\% \text{ Recovery of Specific Flux} = 100\left[1 - \frac{Js_f}{Js_i}\right]$$

where: Js_f = Specific flux (gfd/psi, L/(h-m2)/bar) at end of current run (final)
Js_i = Specific flux (gfd/psi, L/(h-m2)/bar) at beginning of subsequent run (initial).

2) The loss of specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (Js_i) divided by the specific flux (Js_{io}) at time zero, as measured at the initiation of the first filtration run in a series:

$$\% \text{ Loss of Original Specific Flux} = 100\left[1 - \frac{Js_i}{Js_{io}}\right]$$

where: Js_{io} = Specific flux (gfd/psi, L/(h-m2)/bar) at time zero point of membrane testing

The minimum reporting requirements shall include presentation of the following results:

- Flux recovery
  - ⇒ Provide table of post cleaning flux recoveries during each 60 day period of operation
- Cleaning efficacy
  - ⇒ Provide table of cleaning efficacy indicators described above for chemical cleaning procedures performed during each 60 day period of operation
- Assessment of irreversible loss of specific flux and estimation of usable membrane life for costing purposes

9.0 TASK 3: FINISHED WATER QUALITY

9.1 Introduction

Water quality data shall be collected for the feedwater and membrane permeate water as shown in the sampling schedule Table 3, during the membrane test runs of Task 1. At a minimum, the required sampling schedule shown in Table 3 shall be observed by the Field Testing Organization on behalf of the Manufacturer. Water quality goals and target removal goals for the membrane equipment shall be recorded in the FOD.

9.2 Experimental Objectives

The objective of this task is to assess the ability of the membrane equipment to demonstrate the stated rejection capabilities and meet the water quality goals specified by the Manufacturer. A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 3. The actual water quality parameters selected for testing and monitoring shall be stipulated by the Field Testing Organization in the FOD.

9.3 Work Plan

The Manufacturer through their designated Field Testing Organization shall identify the DBP precursor rejection capabilities in the statement of performance capabilities provided in the FOD. In the statement of performance capabilities, the Manufacturer shall identify the specific DBPs that shall be monitored during equipment testing. The statement of performance capabilities prepared by the Manufacturer and their designated Field Testing Organization shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater. Two examples of satisfactory statements for demonstration of water treatment capabilities are provided below:

1. "This packaged plant is capable of achieving 90% removal of dissolved organic carbon (DOC) in feedwaters with organic carbon concentrations between 2.0 and 4.0 mg/L and with feedwater alkalinities less than 60 mg/L as $CaCO_3$."
2. "This packaged plant is capable of achieving 90% removal of precursors to trihalomethanes and haloacetic acids in feedwaters. Removal of THM and HAA precursors will be quantified by comparison of SDS testing results (UFC under the ICR) generated for feed and finished water samples."

It should be noted that many of the packaged and/or modular drinking water treatment systems participating in the DBP Precursor Removal Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this DBP Precursor Protocol and the associated Verification Testing Plans are oriented towards removal of DBP precursors, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters. Furthermore, in light of the fact that the treatment process may alter water quality beyond a simple reduction of precursors to disinfection by-products, the Field Testing Organization shall also required to report and discuss the potential impacts that the treatment process may have on other pertinent water quality characteristics such as pH, hardness, alkalinity, corrosivity, LSI, etc. For example, a treatment process such as reverse osmosis may reduce hardness and alkalinity, increasing the corrosivity of treated waters such that actual systems employing the equipment might have problems meeting lead and copper standards in certain distribution systems.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization (refer to Table 4). Analysis of the remaining water quality parameters shall be performed by a laboratory that is certified, accredited or approved by

a State, a third-party organization (i.e., NSF), or the U.S. EPA. The methods to be used for measurement of water quality parameters in the field are described in the Analytical Methods section below and in Table 4. The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water qualities are described in Task 5, Quality Assurance/ Quality Control (QA/QC). Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at a laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the accredited laboratory that is certified. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

9.4 Analytical Schedule

9.4.1 Removal of Simulated Distribution System (SDS) Precursors to DBPs

During the steady-state operation of each membrane testing period, SDS DBP testing shall be performed on the membrane feedwater and the permeate water in order to determine the precursor removal capabilities of the membrane system. SDS DBP testing shall be used to determine removal of any disinfection by-products (e.g., trihalomethanes, haloacetic acids, haloketones, etc.) identified by the Field Testing Organization in the FOD.

For evaluation of the DBP precursor concentrations, the Field Testing Organization will be permitted to conduct SDS testing at the standard disinfectant conditions of the distribution system of the utility participating in the Verification Testing Program. In the case that no utility-specific simulated distribution system conditions are identified, the Field Testing Organization shall employ the standardized Information Collection Rule (ICR) approach of the Uniform Formation Conditions (UFC) in this Verification Testing Program. This SDS method shall be performed by spiking a water sample with a disinfectant and holding the sample in the dark at the uniform formation conditions (UFC) specified in the ICR Manual for Bench- and Pilot-Scale Treatment Studies. (Refer to the SDS Test Protocol in the QA/QC section of this Verification Testing Plan for further details.) The following UFC may thus be used for DBP formation testing:

- Incubation time: 24 +/- 1 hours
- Incubation temperature: 20.0 +/- 1.0 °C
- Buffered pH: 8.0 +/- 0.2
- 24-hour Chlorine Residual: 1.0 +/- 0.4 mg Cl_2/L

For these conditions, the chlorine dose required to achieve the target chlorine residual can be determined by first conducting a demand study with the water sample. Since the DOC concentrations of a water can vary over the course of a test run, the chlorine demand of a

given water may also vary. The chlorine dose must therefore be varied according to the chlorine demand of the water. Frequency of sampling and SDS DBP analysis shall be specified by the individual test plans used for the Equipment Verification Testing Program and shall also be stipulated in the FOD.

In the case that this Verification Testing Program is performed in conjunction with utility operation, the SDS DBP formation conditions employed for this test plan may be tailored to correspond to the appropriate SDS conditions at the corresponding utility.

9.4.2 Feed and Permeate Water Characterization

At the beginning of the membrane testing period (and thereafter with indicated frequency), the raw water and permeate water shall be characterized at a single set of operating conditions by measurement of the following water quality parameters (as indicated in Table 3):

- alkalinity (twice per month)
- total and calcium hardness (twice per month)
- total dissolved solids (twice per month)
- conductivity (twice per month)
- ortho-phosphate (twice per month)
- sulfate (twice per month)
- chloride (twice per month)
- bromide (twice per month)
- iron & manganese (twice per month)
- silica (total & dissolved) (twice per month)
- SDI of feedwater to high pressure membrane system (twice per month)
- total suspended solids (twice per month)
- total organic carbon (twice per week)
- Color or $UV_{254\ nm}$ absorbance (daily), $UV_{254\ nm}$ shall be collected at least once weekly
- Trihalomethane (THM) concentrations from SDS testing (twice per month)
- Haloacetic acids (HAA6) concentration from SDS testing (twice per month)
- Any additional DBP compounds formed during SDS testing (twice per month). DBP species to be monitored shall be specified by Field Testing Organization in the FOD. Some additional, optional DBPs may include:
  - chloral hydrate
  - chloropicrin
  - haloketones
  - haloacetonitriles
- temperature (daily)
- pH (daily)
- permeate water turbidity (daily)
- feed (and concentrate) water turbidity (daily)
- Total coliform (TC) and heterotrophic plate count (HPC) bacteria (optional testing).

9.4.3 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during the period of membrane testing. The minimum monitoring frequency for the required water quality parameters is provided in Table 3. At the discretion of the Manufacturer and the designated Field Testing Organization, the water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling. Sample collection frequency and protocol shall be defined explicitly by the Field Testing Organization in the FOD; however, to the extent possible, analyses for organic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

No monitoring of microbial populations shall be required in this Equipment Verification Testing Plan. However, the Manufacturer may include optional monitoring of indigenous microbial populations to demonstrate removal capabilities.

Further, microbial removal through seeding studies may be evaluated during the two-month testing period. Refer to Task 8 of Chapter 2 in the "EPA/NSF Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants" for the details of conducting such tests.

9.4.4 Feedwater Quality Limitations

The characteristics of feedwaters encountered during the two-month testing period shall be explicitly reported with the compiled results from membrane flux and product water recovery monitoring. Accurate reporting of such feedwater characteristics as temperature, TOC concentration, UV_{254} absorbance, turbidity, total dissolved solids, pH, alkalinity, and hardness, conductivity, phosphate, and sulfate is critical for the Verification Testing Program, as these parameters can substantially influence membrane performance on a seasonal basis.

9.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal of TOC concentration, UV_{254} absorbance, SDS DBP concentrations
  - ⇒ plot graph of percent removal across the membrane at weekly intervals over each 60-day period of operation for the following water quality parameters: TOC concentration, UV_{254} absorbance, SDS THMs, SDS HAAs, other DBPs stipulated by the Manufacturer. The following equation shall be used to determine percent removal of all organic water quality parameters including TOC, UV_{254} absorbance, and precursors to DBPs:

$$\%\ \text{removal organic materials} = 100\left(1 - \frac{(\text{permeate water concentration})}{(\text{feed water concentration})}\right)$$

⇒ provide feed and permeate levels for TOC, UV_{254} absorbance and monitored DBPs in tabular form for each 60 day period of operation

- Turbidity and total suspended solids
  - ⇒ plot graph of daily feed and permeate turbidity measurements during each 60 day period of operation
  - ⇒ plot graph of daily feed and permeate total suspended solids measurements during each 60-day period of operation
- Water quality and removal goals specified by the Manufacturer
  - ⇒ provide feed and permeate concentrations of any measured water quality parameters in tabular form for each 60 day period of operation
- Optional Task: Removal of indigenous bacteria (Total Coliforms (TC) and HPC)
  - ⇒ provide feed and permeate levels for TC and HPC bacteria in tabular form for each 60 day period of operation
  - ⇒ provide values for TC and HPC log removal in tabular form for each 60 day period of operation
- Impacts of treatment on pertinent water quality parameters
  - ⇒ provide information on impacts of treatment on pertinent water quality parameters not related to DBP precursor removal

10.0 TASK 4: DATA HANDLING PROTOCOL

10.1 Introduction

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets and manual recording of operational parameters for the membrane equipment on a daily basis.

10.2 Experimental Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data for the NSF for verification purposes.

10.3 Work Plan

The following protocol has been developed for data handling and data verification by the Field Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of membrane equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the Field Testing Organization at least once per week during each two-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the membrane equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each membrane test run) shall be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.0 TASK 5: QUALITY ASSURANCE/QUALITY CONTROL

11.1 Introduction

Quality assurance and quality control of the operation of the membrane equipment and the measured water quality parameters shall be maintained during the verification testing program.

11.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

11.3 Work Plan

Equipment flowrates and associated signals should be documented and recorded on a routine basis. A routine daily walk through during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to confirm that any chemicals are being fed at the defined flowrate into a flowstream that is operating at the expected flowrate, such that the chemical concentrations are correct. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e. flowrate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

11.4 Daily QA/QC Verifications

- Chemical feed pump flowrates (verified volumetrically over a specific time period)
- In-line turbidimeter flowrates (verified volumetrically over a specific period of time, if employed).
- In-line turbidimeter readings checked against a properly calibrated bench model.

11.5 QA/QC Verifications Performed Every Two Weeks

- In-line flowmeters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

11.6 QA/QC Verifications for Each Testing Period

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)

11.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water quality are described in the section below. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

11.7.1 pH

Analyses for pH shall be performed according to Standard Method 4500-H^+ B or EPA Method 150.1/150.2. A 2 point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution

defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss with the atmosphere.

11.7.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Method* 2550. The thermometer shall have a scale marked for every 0.1 ^{o}C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1^{o}C to +51^{o}C, subdivided in 0.1^{o} increments, would be appropriate for this work.)

11.7.3 UV_{254} Absorbance

Analysis of UV_{254} shall be performed according to *Standard Method* 5910 B. The maximum allowable holding time for *Standard Method* 5910 B is 48 hours. Therefore, it is recommended that UV_{254} samples be analyzed on-site by the Field Testing Organization with an UV spectrophotometer at 254 nm.

11.7.4 Turbidity

Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters are recommended for measurement of turbidity in the treated water, and either an in-line or a bench-top turbidimeter may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Bench-top Turbidimeters: Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of pilot plant operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples dial cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

In-line Turbidimeters: In-line turbidimeters must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

11.8 Chemical and Biological Samples Shipped Off-Site for Analyses

The analytical methods that shall be used during testing for chemical and biological samples that are shipped off-site for analyses are described in the section below.

11.8.1 Inorganic Samples

Inorganic chemical samples shall be collected and preserved in accordance with *Standard Method* 3010B, if applicable, paying particular attention to the sources of contamination as outlined in *Standard Method* 3010C. The samples shall be refrigerated at approximately 4^{o}C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4^{o}C during shipment. Samples shall be held and processed for analysis by a State or EPA-accredited laboratory in accordance with *Standard Methods*. The laboratory shall keep the samples at approximately 4^{o}C until initiation of analysis.

Alkalinity analyses shall be performed according to Standard Method 2320 B. Calcium hardness analyses shall be performed according to Standard Method 3500-Ca D. Total hardness analyses shall be performed according to Standard Method 2340 C.

11.8.2 Organic Samples: TOC

TOC analyses shall be performed according to Standard Method 5310 C. Samples for analysis of TOC collected in amber glass bottles with TFE-lined septa supplied by the state or EPA accredited laboratory. The appropriate preservative as indicated by the State or EPA accredited laboratory shall be added. The samples shall be shipped overnight with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by the state or EPA accredited laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 4°C until initiation of analysis.

11.8.3 DBPs Samples

DBPs samples shall be collected, preserved (if applicable), held, and analyzed in accordance with the appropriate Standard Method.

11.8.4 Optional Monitoring: Microbial Parameters (Total Coliforms and Heterotrophic Plate Count Bacteria)

Collection of samples for Total Coliforms (TC) and Heterotrophic Plate Count (HPC) bacteria is optional in this test plan. Samples for analysis of TC and HPC bacteria shall be collected in bottles supplied by the State or EPA accredited laboratory and shipped with an internal cooler temperature of approximately 2-8°C to the analytical laboratory. Samples shall be processed for analysis by the state or EPA accredited laboratory within 24 hours of collection. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities shall be reported as colony forming units per milliliter (cfu/mL).

11.9 Simulated Distribution System (SDS) Test Protocol

The simulated distribution system (SDS) disinfection by-products (DBP) test simulates full-scale disinfection by spiking a water sample with a disinfectant and holding the spiked sample in the dark at a designated temperature and contact time. For this testing, one of two SDS approaches may be employed. The conditions selected for SDS evaluation may be those that most closely approximate the detention time and chlorine residual in the distribution system at the site of verification testing. Alternatively, the uniform formation conditions (UFC) specified by the ICR will be adopted such that the following set of conditions will be employed:

- incubation period of 24 +/- 1 hours,
- incubation temperature of 20 +/- 1.0 °C,
- buffered pH of 8.0 +/- 0.2,
- 24-hour chlorine residual of 1.0 +/- 0.4 mg Cl_2/L.

For each SDS sample, three incubation bottles will be set up. At the end of the incubation period, each sample will be analyzed for the final disinfectant residual and the sample with the residual closest to the 1.0 +/- 0.4 mg/L range will be used for specified DBP analyses. Analysis

for DBPs specified by the Manufacturer shall be performed by an State or EPA accredited laboratory according to the Standard Methods procedures appropriate for the designated DBPs. In the case that this Verification Testing Plan for removal of precursors to DBPs is conducted in conjunction with utility operation, the SDS or DBP formation conditions employed for this test plan may be tailored to correspond to the appropriate SDS conditions at the corresponding utility.

One liter, amber colored bottles with Teflon lined caps shall be used to store the SDS samples during incubation. These bottles shall be stored in a temperature-controlled incubator at the specified temperature.

All glassware used for preparation of the reagents shall be chlorine demand free. Chlorine demand free glassware shall be prepared by soaking glassware in a 50 mg/L chlorine bath for a period of 24 hours. At the end of this time, all glassware shall be rinsed three times with organic-free water that has a TOC concentration of less than 0.2 mg/L. Glassware shall then be dried at room temperature for a period of 24 hours. During the drying process, bottle openings shall be covered with aluminum foil to prevent contamination.

The reagents preparation and sample measurement shall proceed as follows.

11.9.1 Chlorine Stock Solution Preparation. The stock solution shall be prepared by adding an estimated volume of 6% reagent-grade NaOCl into a 500-mL, chlorine demand free, bottle containing an estimated amount of organic-free water. To minimize the dilution error, the chlorine stock solution shall be required to be at least 50 times stronger than the chlorine dose required.

11.9.2 Preparation of Additional Chemicals. Refer to Standard Method 4500-Cl F for the preparation method of DPD indicator, FAS standard and buffer solution. The phosphate buffer solution shall be prepared as instructed in Standard Method 4500-Cl F.

11.9.3 Sample Collection and Incubation. The samples shall be collected in a 1-L amber bottle and stored in the dark at the predetermined temperature. Samples shall be adjusted to pH 8.0 +/- 0.2 using 1M HCl or NaOH and then be dosed with the appropriate dosage of chlorine to yield a chlorine residual of 1.0 +/- 0.4 mg Cl_2/L after the specified 24-hour storage period. The samples shall be capped head-space free and stored for 24 hours in the dark at the appropriate incubation temperature.

11.9.4 Analytical Measurements. Residual free chlorine measurements shall be conducted according to Standard Methods 4500-Cl G. DPD Colorimetric Method. Specific parameters to be measured and recorded are outlined in the specific task descriptions.

12.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied operations and maintenance (O&M) manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for membrane process package plants that are designed to achieve removal of precursors to disinfection by-products.

12.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- pressure gauges
- backwash controls
- flow meters
- air compressors
- chemical feeder systems
- mixers
- motors
- instruments, such as streaming current monitors or turbidimeters
- water meters, if provided

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating such as:

- tanks and basins
- in-line static mixers
- tubing and hoses

12.2 Operation

The Manufacturer should provide readily understood recommendations for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are:

Filtration:

- control of feed flow to the membrane system
- measurement of inlet/outlet pressures and filtrate flows
- measurement of transmembrane pressure changes during filter run
- feed flow control in response to temperature changes

Membrane backwashing:

- programming automated frequency
- proper backwash venting and disposal

- appropriate backwash rate (if applicable)
- monitoring during return of filter to service

Chemical cleaning:
- selection of proper chemical washing sequence
- proper procedures for dilution of chemicals
- monitoring of pH through chemical cleaning cycle
- rinsing of membrane system following chemical clean
- return of filter to service

Chemical feeders (in the case that chemical pretreatment is applied):
- calibration check
- settings and adjustments -- how they should be made
- dilution of chemicals and polymers -- proper procedures

Monitoring and observing operation:
- observation of feedwater or pretreated water turbidity
- observation of transmembrane pressure increase between backwashes
- filtered water turbidity
- filter head loss
- what to do if turbidity breakthrough occurs

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:
- no raw water (feedwater) flow to plant
- can't control rate of flow of water through package plant
- valving configuration for direct flow and cross-flow operation modes
- poor filtrate quality
- failed membrane test
- low pump feed pressure
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- head loss builds up excessively rapidly
- reduced filtrate flux
- machine will not start and “Power On” indicator off
- machine will not start and “Power On” indicator on
- pump cavitation
- valve stuck or won't operate
- no electric power
- no chemical feed
- no antiscalant addition

The following are recommendations regarding operability aspects of package plants that are designed to achieve removal of disinfection by-product precursors. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to

the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program.

During verification testing and during compilation of historical package plant operating data, attention shall be given to package plant operability aspects. Among the factors that should be considered are:

- fluctuation of flow rates and pressures through membrane unit -- the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- presence of devices to aid the operator with flow control adjustment and chemical dosage selection:
  - influent and filtered water continuous turbidimeters provided?
  - continuous particle counter provided on membrane filtered water?
  - can backwash be done automatically?
- if automatic backwash provided, could it be initiated by:
  - reaching a set value for head loss?
  - reaching a set value for filtered water turbidity?
  - a preset automatic timer?
- does remote notification to operator occur when backwash happens?
- can operator observe backwash?
- does plant have multiple feed points for chemicals:
  - for pH adjustment?
  - for coagulant chemical feed?
  - for antiscalant addition?
- is transmembrane pressure measurement provided?
- is rate of flow of raw water measured?
- are chemical feeds paced with raw water flow?
- is backwash rate of flow measured and variable?
- is backwash duration (time) variable?

The report on Verification Testing should address the above questions. The issues of operability should be dealt with in the portion of the report that is written in response to Tasks 1 & 2 of the Membrane Process Test Plan addressing the Removal of Precursors to Disinfection By-Products.

13.0 REFERENCES

Streeter, V. L. and E. B. Wiley. 1985. Fluid Mechanics, 8th ed. New York, McGraw Hill Book Company.

U.S. EPA, 1989. Guidance Manual for Compliance with Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, Cincinnati, OH. Science and Technology Branch.

U.S. EPA, 1990. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Waters. American Water Works Association, Washington, D.C.

U.S. EPA, 1996. ICR Manual for Bench- and Pilot-Scale Treatment Studies. Office of Ground Water and Drinking Water, Cincinnati, OH. Technical Support Division.

Table 1.
Task Descriptions

Task No.	Task	Testing Periods (minimum)	Issue	Test
Membrane Verification Testing Study				
1	Membrane Flux and Operation	1	Rate of Specific Flux Decline	Evaluate productivity at selected set of operational conditions
2	Cleaning Efficiency	1	Cleaning Efficiency	Clean system following fouling
3	Finished Water Quality	1	Finished Water Quality & rejection capabilities	Measure permeate WQ and document rejection capabilities
4	Data Handling Protocol		Careful Recording of testing data	
5	QA/QC		Enforcement of QA/QC Standards	

Table 2.
Operational Data Collection Schedule

Location	Operational Data	Minimum Frequency
Raw Water		
	Flow	2/day
	Temperature	1/day
Single-Stage Membrane Processes		
	Influent module/vessel pressure	2/day
	Effluent module/vessel pressure	2/day
	Permeate pressure	2/day
	Permeate flow	2/day
	Permeate Temperature	1/day
	Concentrate Flow	2/day
Multiple-Stage Membrane Processes		
	Stage 1 Influent module pressure	2/day
	Stage 1 Effluent module pressure	2/day
	Stage 1 Influent module temperature	1/day
	Stage 1 Feed flow	2/day
	Stage 1 Permeate pressure	2/day
	Stage 1 Permeate flow	2/day
	Stage 1 Permeate temperature	1/day
	Stage 1 Crossflow velocity	2/day
	Stage 1 Effluent module flow	2/day
	Stage 2 Influent module pressure	2/day
	Stage 2 Effluent module pressure	2/day
	Stage 2 Influent module temperature	1/day
	Stage 2 Feed flow	2/day
	Stage 2 Permeate pressure	2/day
	Stage 2 Permeate flow	2/day
	Stage 2 Permeate temperature	1/day
	Stage 2 Crossflow velocity	2/day
	Stage 2 Concentrate flow	2/day

Note: It is recognized that different manufacturer membrane configurations shall have appropriate sampling locations and measurement points according to the particular geometry of the membrane system. Membrane performance will be best evaluated from these sampling points; therefore, this data collection schedule should be adapted to the Manufacturer's particular configuration and operational process.

Table 3.
Water Quality Sample Schedule

Parameter	Sampling Frequency	Single Stage Process			Multiple Stage Process				
					Stage 1			Stage 2	
		Feed	Permeate	Backwash Waste	Feed	Permeate	Concentrate	Permeate	Waste
On-Site Analytes									
pH	Daily	1	1	1	1	1	1	1	0
Temperature	Daily	1	0	0	1	0	0	0	0
Turbidity*	Daily	1	1	1	1	1	1	1	1
Laboratory Analytes									
Alkalinity	Monthly	2	2	0	2	2	2	2	0
Total/calcium hardness	Monthly	2	2	0	2	2	2	2	0
TOC	Weekly	2	2	1	2	2	2	2	1
UV_{254} or Color**	Daily	1	1	0	1	1	1	1	0
TSS	Monthly	2	2	2	2	2	2	2	2
TDS	Monthly	2	2	0	2	2	2	2	0
Ortho-phosphate	Monthly	2	2	0	2	2	2	2	0
Sulfate	Monthly	2	2	0	2	2	2	2	0
Iron	Monthly	2	2	0	2	2	2	2	0
Manganese	Monthly	2	2	0	2	2	2	2	0
Silica (total and dissolved)	Monthly	2	2	0	2	2	2	2	0
Chloride	Monthly	2	2	0	2	2	2	2	0
Bromide	Monthly	2	2	0	2	2	2	2	0
Conductivity	Monthly	2	2	0	2	2	2	2	0
SDI	Monthly	2	0	0	2	0	0	0	0
Total coliforms (optional)	Weekly	1	1	1	1	1	1	1	1
HPC (optional)	Weekly	1	1	0	1	1	1	1	0
SDS Testing (Optional Selection of Monitored DBPs)									
Total Trihalomethanes	Monthly	2	2	0	2	2	1	2	0
Haloacetric Acids (6)	Monthly	2	2	0	2	2	1	2	0
Chloral Hydrate	Monthly	2	2	0	2	2	1	2	0
Chloropicrin	Monthly	2	2	0	2	2	1	2	0
Haloketones	Monthly	2	2	0	2	2	1	2	0
Haloacetonitriles	Monthly	2	2	0	2	2	1	2	0
Other specified DBPs	Monthly	2	2	0	2	2	1	2	0

*Daily batch sampling or continuous monitoring may be employed for measurement of turbidity.
**UV_{254} or color needs to be measured daily; however, at least one measurement per week needs to be UV_{254}.
Note: The Manufacturer should adapt the operational data collection location to the particular configuration of the membrane system.

Table 4.
Analytical Methods

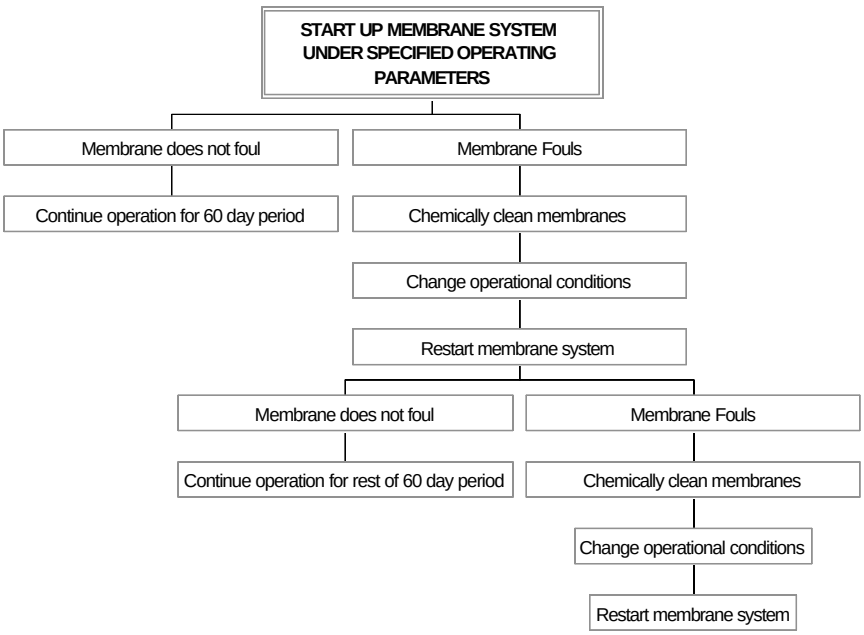
Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total organic carbon	Lab	5310 C	
Turbidity	On-Site	2130 B / Method 2	180.1
Dissolved Oxygen	On-Site	4500-O	
Iron	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
Manganese	Lab	3111 D / 3113 B / 3120 B	200.7 / 200.8 / 200.9
UV_{254} absorbance	Lab	5910 B	
Calcium Hardness	Lab	3500-Ca D	
Total Dissolved Solids	Lab	2540 C	
Total Suspended Solids	Lab	2540 D	
Conductivity	Lab	2510 B	120.1
Ortho-phosphate	Lab	4500P-E	365.1
Sulfate	Lab	4110 B/4500-SO_4^+C, D, F	300.0
Silica (total and dissolved)	Lab	3120 B/4500-Si D, E, F	200.7
Chloride	Lab	4110 B/4500-Cl^- D	300.0
Bromide	Lab		300.0
Total THMs	Lab		502.2, 524.2, 551
Haloacetic Acids (HAA6)	Lab		552.1
Chloral Hydrate	Lab	5710 D	
Chloropicrin	Lab	5710 D	
Haloketones	Lab	5710 D	
Haloacetonitriles	Lab	5710 D	
Other specified DBPs	Lab	5710 D or other specified method	
TC and HPC	Lab	9215 B	

Notes:

1) Standard Methods Source: 18th Edition of Standard Methods for the Examination of Water and Wastewater, 1992, American Water Works Association.

2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Figure 1
Schematic of Membrane Operational Plan



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CHAPTER 3

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN FOR GRANULAR ACTIVATED CARBON ADSORPTION OF DISINFECTION BY-PRODUCT PRECURSORS

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1.0 APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN

This document is an NSF Equipment Verification Testing Plan for granular activated carbon (GAC) adsorption to be used within the structure provided by the NSF Protocol document: "Protocol For Equipment Verification Testing of Disinfection By-Product Precursor Removal By Package And/Or Modular Drinking Water Treatment Systems." This Testing Plan is to be used as a guide in the development of a Field Operations Document for testing of GAC adsorption equipment to achieve removal of precursors of disinfection byproducts (DBPs). Refer to the "Protocol For Equipment Verification Testing of Disinfection By-Product Precursor Removal By Package And/Or Modular Drinking Water Treatment Systems" for further information.

In order to participate in the equipment verification process for GAC adsorption, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of a Field Operations Document (FOD). The FOD should generally follow those Tasks outlined herein, with changes and modifications made for adaptations to specific GAC adsorption equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction
- Experimental Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing Program is to achieve removal of DBP precursors present in water supplies such that finished waters are of acceptable water quality. The driving force for the goal of precursor removal is to achieve compliance with any future Disinfectant/Disinfection By-Product (D/DBP) regulations under the Safe Drinking Water Act. The experimental design of the FOD shall therefore be developed so the relevant questions about water treatment equipment capabilities can be answered. Each FOD shall include all of the included tasks, Tasks 1 to 5.

2.0 INTRODUCTION

Adsorption by GAC can be an effective treatment technique for removing DBP precursors prior to disinfection application. GAC contactors are operated as filters usually containing a 12x40 or 8x30 US Standard Mesh size GAC. They can be operated after rapid sand filtration (post-filter adsorber) or as a filter-adsorber, in which the GAC contactor also acts as a filter of particulate matter, and therefore must be backwashed after increases in headloss. Typical empty-bed contact times (EBCTs) are 10 to 30 minutes for post-filter adsorbers, and 5 to 10 minutes for filter-adsorbers.

GAC adsorption is an unsteady-state process. DBP precursor removal, as measured by total organic carbon (TOC) or ultraviolet absorbance at 254 nm (UV_{254}), is typically greater than 85

percent at the beginning of contactor operation for EBCTs greater than 10 minutes. Over time, effluent concentrations increase, yielding a characteristic breakthrough curve that is unique to the water source, pretreatment conditions, EBCT, and type of GAC used. Breakthrough curves can also be developed for DBP precursors by chlorinating GAC effluent samples. Thus, the GAC contactor run time to a given effluent criterion can be determined from the appropriate breakthrough curve. Once effluent criteria are exceeded, the GAC must be replaced with new or reactivated GAC.

This Verification Testing Plan is not designed to evaluate the removal of preformed DBPs by GAC in treatment systems employing prechlorination. This Verification Testing Plan is designed to evaluate GAC performance for the removal of the precursors to DBPs formed by chlorination after GAC adsorption.

Continuous chlorine addition prior to GAC adsorption should be avoided when possible. GAC removes chlorine, and therefore chlorine must be reapplied after GAC to maintain a disinfectant residual in the distribution system. Chlorine added prior to GAC adsorption increases the level of DBPs in the finished water, while decreasing the ability of GAC to adsorb DBP precursors.

The test protocol has been designed to assess the GAC adsorption capacity. When utilizing the rapid small-scale column test (RSSCT), long-term biological removal of DBP precursors by GAC may not be well simulated, due to relatively short run times. However, unless preozonation is practiced, biological activity in a GAC column can effectively remove only 10 to 20 percent of the TOC or dissolved organic carbon (DOC) in groundwaters or treated surface waters. The remainder of the TOC removed is often attributed to bioactivity (another 5 to 10 percent), but is actually due to slow adsorption. The RSSCT has been calibrated and verified with the data from at least 30 full- or pilot-scale GAC columns (Summers et al., 1995). Since biological activity is inherent in all full- and pilot-scale GAC columns, its removal contribution does not seem to impact the breakthrough curve enough to warrant special consideration; the RSSCT well-simulates the breakthrough curve of non-preozonated waters. If, due to treatment processes in place prior to GAC (such as ozonation) or past experience with the water to be tested, it is felt that biological activity will play a significant role in determining GAC efficiency, then it is recommended that the package plant be utilized during testing.

This Verification Testing Plan is not intended to be used for the evaluation of ability of GAC to serve as a particulate matter (turbidity) filter. The NSF Equipment Verification Testing Plan for Coagulation and Filtration should be used in conjunction with this Testing Plan when verification of particulate matter filtration performance is required.

3.0 GENERAL APPROACH

This Verification Testing Plan is centered on completion of two main tasks: System Integrity Verification Testing and Adsorption Capacity Verification Testing. System Integrity Verification Testing is a two-week field operation of the package plant with monitoring to ensure the system is functional and to identify any major systemic problems such as channeling, insufficient media, excessive headloss buildup, etc. This Testing Plan includes sampling and

monitoring requirements for System Integrity Verification Testing. Adsorption Capacity Verification Testing is intended to evaluate the ability of the type of GAC and contact time utilized to remove DBP precursors to the level stated by the FTO. Such a statement by the FTO might be phrased as: "This package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of achieving an effluent TOC concentration below 2.0 mg/L for at least 50 days for GAC influent TOC concentrations between 3.0 and 4.0 mg/L and influent pH less than 8.0."

Testing shall be conducted by an NSF-qualified Field Testing Organization that is selected by the Manufacturer. Water quality analytical work to be completed as part of this NSF Equipment Verification Testing Plan shall be contracted with an NSF-approved laboratory.

The influent water quality chosen for Adsorption Capacity Verification Testing should reflect the claims the Manufacturer intends to make on the package plant performance. Multiple claims made on the ability of a package plant to treat a variety of influent water quality conditions must be supported by Adsorption Capacity Verification Testing performed under conditions representative of this range of water quality. Adsorption Capacity Verification Testing must be conducted at least once using the package plant. Subsequent testing may be performed in the field using the package plant or in a laboratory using the rapid small-scale column test (RSSCT), a rapid bench-scale GAC test. The RSSCT shall be designed to simulate the EBCT of the package plant and shall use a representative sample of the GAC used in the package plant.

The manufacturer shall stipulate which pretreatment processes are necessary prior to GAC adsorption. The recommended pretreatment processes shall then be employed as pretreatment during Equipment Verification Testing. GAC adsorption performance will be evaluated based on GAC influent water quality, sampled after any pretreatment processes. If Adsorption Capacity Verification Testing is conducted using RSSCTs, any Manufacturer recommended pretreatment processes must be simulated prior to the RSSCT. Alternatively, the water used as influent to the RSSCT may be sampled from a package plant or full-scale treatment plant employing representative recommended pretreatment process.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the tasks included in the GAC Verification Testing Plan.

4.1 Task 1: System Integrity Verification Testing

The objectives of this task are to demonstrate that the package plant is (1) able to initially produce a finished water of acceptable quality, and (2) able to reliably operate under field conditions. The package plant is operated, monitored, and sampled for approximately two weeks.

4.2 Task 2: Adsorption Capacity Verification Testing

The objectives of this task are to evaluate the ability of the GAC package plant to meet the water quality objectives specified by the Manufacturer. The performance of the GAC package plant is a function of the type of GAC used and the influent water quality. Adsorption Capacity Verification Testing must be repeated, as necessary, using different water sources to verify the ability of the package plant to meet multiple treated water quality objectives stated by the Manufacturer. GAC influent and effluent DBP precursor surrogate analyses performed include TOC and UV_{254}. DBP precursor removal will also be assessed, by chlorination of GAC influent and effluent water samples. The duration of testing will depend on treatment goals supplied by the Manufacturer. Adsorption Capacity Verification Testing shall be performed at least once using the package plant. Thereafter, the RSSCT may be utilized for Adsorption Capacity Verification Testing.

4.3 Task 3: Documentation of Operating Conditions and Treatment Equipment Performance

During each day of Verification testing, operating conditions shall be documented. This shall include descriptions of any pretreatment processes and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including rate of filter head loss gain and frequency and duration of filter washing for GAC contactors operated as filter-adsorbers. The volumetric flow rate through a GAC contactor is a critical parameter, and shall be frequently monitored, recorded, and adjusted if necessary. GAC performance is affected by the EBCT, which is a function of the volumetric flow rate through the contactor.

4.4 Task 4: Data Management

This task will establish effective field protocol for data management at the field operations site and for data transmission between the Field Testing Organization and the NSF.

4.5 Task 5: Quality Assurance/Quality Control

The objective of this task is to ensure accurate measurement of operational and water quality parameters during Verification testing.

5.0 TESTING PERIODS

Task 1, System Integrity Verification Testing, is designed to be carried out in conjunction with Tasks 3 through 5 in a two-week period, not including mobilization and start-up. Task 2, Adsorption Capacity Verification Testing, is designed to be carried out in conjunction with Tasks 3 through 5. The duration of Task 2 is dependent on the run time required to verify Manufacturer's treatment claims, the source water quality, and whether testing is conducted using a package plant or the RSSCT. The expected duration of Adsorption Capacity Verification Testing may range from 1 to 6 months. Adsorption Capacity Verification Testing performed using the rapid bench-scale GAC test (RSSCT) decreases the testing period to between 5 and 15

percent of package plant testing, not including experimental design and set-up, obtaining a water source, and bench-scale pretreatment, if necessary.

6.0 DEFINITIONS

6.1 Bed volume: a normalized unit of throughput, run time divided by EBCT.

6.2 Breakthrough curve: a characteristic profile of a GAC adsorber. The effluent concentration of a parameter is plotted over time, typically showing a small amount of immediate breakthrough, a point of initial breakthrough where the effluent concentration begins to steadily increase over the immediate breakthrough, and a diminishing rate of increase over time.

6.3 BV_{50}: throughput in number of bed volumes treated to 50 percent TOC breakthrough

6.4 Empty-bed contact time (EBCT): retention time in an empty contactor

6.5 Immediate breakthrough: a fraction of natural organic matter that is nonadsorbable, and can be quantified in the GAC effluent immediately after startup, usually at very low levels (0.1 - 0.5 mg/L TOC, typ.)

6.6 Initial breakthrough: the point in GAC run time when effluent concentrations begin to increase above the nonadsorbable fraction concentration.

6.7 Rapid small-scale column test (RSSCT): a scaled version of a GAC adsorber, utilizing a smaller particle size GAC, designed with scaling equations which maintain similitude to the full-scale system.

6.8 Run time: the operation time of a GAC contactor to a given effluent criterion. For a package plant, the run time is given in days. For a RSSCT, actual laboratory run time is converted to "full-scale equivalent run time," due to the scaled design of the RSSCT.

6.9 t_{50}: run time to 50 percent TOC breakthrough

7.0 TASK 1: SYSTEM INTEGRITY VERIFICATION TESTING

7.1 Introduction

This task will evaluate the short-term ability of the package plant to produce water of acceptable quality. This task is not designed to evaluate the long-term ability of the package plant to remove DBP precursors.

7.2 Experimental Objectives

The objectives of this task are to demonstrate that the package plant is (1) able to initially produce a finished water of acceptable quality, and (2) able to reliably operate under field conditions.

7.3 Work Plan

The Manufacturer and their designated FTO shall specify the operating conditions to be evaluated during verification testing and shall supply written procedures on the operation and maintenance of the treatment system. To complete the System Integrity Test, the treatment system shall be operated continuously for a minimum of 344 hours (14 full days plus one 8-hour work shift). For GAC contactors operated in a filter-adsorber mode, the treatment equipment shall be operated from start-up until turbidity breakthrough or terminal head loss is attained, at which time the contactors shall be backwashed and operation shall resume. For GAC contactors operated as post-filter adsorbers, the media filters in-line upstream of the GAC contactors shall be operated from start-up until turbidity breakthrough or terminal head loss is attained, at which time the media filters shall be backwashed and operation shall resume. In either case, System Integrity Verification Testing shall include at least one backwashing event, as determined by turbidity breakthrough or terminal headloss. Verification testing using a water source that requires filter backwashing every 1 to 4 days is recommended. Interruptions in the treatment system shall be documented and are allowed only for backwashing events and required equipment maintenance. Since GAC performance is a function of EBCT, which is dependent on the volumetric flow rate, it is critical that verification testing be conducted at a set flow rate that is maintained within 5 percent of the design value.

GAC contactors operated as filter-adsorbers must meet NSF Verification Testing for Filtration to be verified as a filter of particulate matter.

Water Quality Sample Collection. Water quality data shall be collected at regular intervals as described below in the Analytical Schedule. Additional or more frequent analyses may be stipulated at the discretion of the FTO. Sample collection frequency and protocol shall be defined by the FTO in the FOD.

In the case of water quality samples to be shipped to the state-certified or third party- or EPA-accredited, off-site laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the off-site laboratory. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory. Acceptable methods for the required analytical procedures are described in Task 5, Quality Assurance/Quality Control.

7.4 Analytical Schedule

7.4.1 Operational Data Collection

The FTO shall provide written procedures describing the operational parameters that should be monitored, monitoring points, and the frequency of monitoring. Such operational parameters shall include at a minimum system flow rates and head loss or pressure. The FTO shall include acceptable values and ranges for all operational parameters monitored.

7.4.2 Water Quality Data Collection

During System Integrity Testing, the GAC influent (feed) water quality and GAC effluent water quality shall be characterized by analysis of the water quality parameters listed in Table 1.

The first sampling for each required analyte shall be performed one day after plant operation start-up, and then by the frequency given. Although many parameters may be analyzed off-site, pH, temperature, and turbidity must be analyzed on-site. It is recommended that UV_{254} be also analyzed on-site.

The above water quality parameters are listed to provide State drinking water regulatory agencies with background data on the quality of the feed water being treated and the quality of the treated water. These data are to be collected to enhance the acceptability of the System Integrity Verification Testing to a wide range of drinking water regulatory agencies.

7.5 Evaluation Criteria and Minimum Reporting Requirements

The results of System Integrity Verification Testing shall be evaluated based on TOC and UV_{254} removal. For filter-adsorbers, turbidity removal shall also be evaluated. The Coagulation and Filtration Verification Testing Protocol shall be followed if the filter-adsorber is to be verified as a filter of particulate matter. Time series plots shall be generated describing GAC influent and effluent TOC, GAC influent and effluent UV_{254}, and GAC influent and effluent turbidity.

The removal by GAC of TOC and UV_{254} is indicative of the removal of DBP precursors: formed DBP breakthrough generally parallels TOC and UV_{254} breakthrough for a given water. The System Integrity Verification Testing should yield high percent removals of these analytes (low immediate breakthrough), demonstrating the initial ability of GAC to very effectively remove DBP precursor material. High levels of immediate breakthrough of TOC and UV_{254} are indicative of failure of the treatment system to initially remove DBP precursors, possibly due to hydraulic channeling, insufficient media, very low GAC adsorption capacity, or inappropriate GAC contactor design for the water quality tested. Long term DBP precursor control will be evaluated during Task 2 (Adsorption Capacity Verification Testing).

8.0 TASK 2: ADSORPTION CAPACITY VERIFICATION TESTING

8.1 Introduction

The purpose of System Integrity Verification Testing is to quickly and efficiently test the basic ability of the GAC contactor system (1) to initially yield a treated water of acceptable water quality and (2) to reliably operate under field conditions. Once this has been demonstrated, the long term effectiveness of the treatment system to remove DBP precursors shall be evaluated by Adsorption Capacity Verification Testing.

GAC treatment is an unsteady-state process whose ability to remove DBP precursors will diminish over time. The breakthrough of DBP precursors for a given water source is characteristic of the treatment system and will depend on design, EBCT, the type of GAC used, and influent water quality. Breakthrough is highly dependent on the concentration and adsorbability of DBP precursors to be treated by GAC. The Manufacturer may make multiple claims on the DBP precursor removal ability of the package plant, since GAC performance is dependent on influent water quality. To verify these claims, the FTO shall repeat Adsorption Capacity Verification Testing, utilizing multiple water qualities representative of those described in the claims, as described below in the Work Plan.

Adsorption Capacity Verification Testing shall be performed at least once for a package plant, but may be performed multiple times on different water qualities to verify the Manufacturer's claims made on the ability of the package plant to remove DBP precursors under various influent water quality conditions.

After initial Adsorption Capacity Verification Testing is performed using the package plant, subsequent Adsorption Capacity Verification Testing may be performed either using the package plant or the rapid small-scale column test (RSSCT). The RSSCT is a scaled version of a GAC adsorber, utilizing a smaller particle size GAC, designed with scaling equations that maintain similitude to the full-scale system. A proportional diffusivity approach is used as diffusion to adsorption sites has been shown to be proportional to the GAC particle size. Therefore, run times to GAC effluent criteria are shortened by a factor proportional to the ratio of the full-scale GAC particle size to the RSSCT GAC particle size. The main advantage of the RSSCT approach is that run times are shortened to 5-20 percent of full-scale run times. A relatively small amount of water is needed, which can be transported to an off-site laboratory. Furthermore, the RSSCT approach does not require an evaluation of adsorption capacity and kinetics by separate experiments or the use of numerical or analytical models (Summers et al., 1995).

One drawback of the RSSCT stems from the use of a batch influent water sample: a single RSSCT experiment will not show the effects of long-term seasonal variability that may be captured during a full-scale run. The selection of a representative batch water sample for the RSSCT is extremely important as changes in influent concentration and adsorbability can lead to misleading results as compared to full-scale GAC adsorber results. Removal of DBP precursors in a full-scale GAC contactor by biodegradation may not be simulated by an RSSCT, due to relatively short run times required by the RSSCT.

After initial Adsorption Capacity Verification Testing is performed using the package plant, Adsorption Capacity Verification Testing may be performed either by use of the package plant treatment system, or by RSSCTs designed to simulate the treatment conditions utilized in the package plant. Manufacturers interested in verifying multiple claims based on treatment of varying GAC influent water qualities may find that Adsorption Capacity Verification Testing performed using a series of RSSCTs will decrease the time and effort required to assess system performance for DBP precursor removal.

8.2 Experimental Objectives

The objectives of this task are to evaluate the ability of the GAC contactors and treatment system to meet the water quality objectives specified by the Manufacturer.

The FTO shall identify the treated water quality objectives to be achieved in the statement of performance capabilities of the equipment to be evaluated during verification testing. The Manufacturer shall also identify in the statement of performance capabilities the specific DBPs that shall be monitored during verification testing. The statement of performance capabilities prepared by the Manufacturer shall indicate the range of water quality under which the equipment can be challenged while successfully treating the GAC influent water. Two examples of satisfactory statements for demonstration of water treatment capabilities are provided below:

1. "This package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining an treated water TOC concentration below 1.0 mg/L for up to 60 days in GAC influent waters with TOC concentrations between 2.0 and 3.0 mg/L and with GAC influent water pH below 8.0."
2. "This package plant, when operated at a GAC EBCT of 15 minutes or more, is capable of maintaining treated water formed total trihalomethanes and the sum of six haloacetic acids under uniform formation conditions below 40 and 30 µg/L, respectively, for up to 60 days in GAC influent waters with TOC concentrations between 2.0 and 3.0 mg/L and with GAC influent water pH below 8.0."

8.3 Work Plan

The FTO shall specify run time criteria for each Adsorption Capacity Verification Testing period. Run time criteria can be based on treated water quality conditions, or set to a specific maximum run time. For example, the FTO may specify that the equipment be operated until the effluent TOC concentration reaches 2.0 mg/L. Alternatively, the FTO may specify a maximum run time of 60 days. A combination of treated water quality and maximum run time criteria may also be utilized.

The run time criteria chosen should reflect the claimed treatment capability of the system, based on the GAC influent water quality. Therefore, water sources must be chosen carefully so that water qualities are representative of that upon which the Manufacturer's treatment capabilities are based. Specifically, the measured influent formed DBP concentration or DBP precursor surrogate concentration (e.g., TOC) during verification testing must average within 20 percent of the amount stated in the Manufacturer's treatment claim. This stipulation ensures that Adsorption Capacity Verification Testing adequately tests the package plant's ability to meet

Manufacturer's claims for a given water quality. Multiple Adsorption Capacity Verification Testing periods will be necessary to provide verification testing on multiple treatment capability claims. For example, a minimum of five Adsorption Capacity Verification Testing runs are required to inclusively verify water treatment claims made on water qualities with GAC influent TOC concentrations ranging between 1.0 and 7.0 mg/L. GAC performance is also affected by the pH of the GAC influent water. Therefore, Adsorption Capacity Verification Testing shall be performed at a GAC influent pH as close as possible to the pH stated in the water treatment claim. A tolerance of ± 0.2 pH units is acceptable.

8.3.1 Package Plant Operation

In assessing package plants, Adsorption Capacity Verification Testing may begin simultaneously with System Integrity Verification Testing. Subsequent sessions of Adsorption Capacity Verification Testing will not require System Integrity Verification Testing. The FTO shall specify the operating conditions to be utilized during verification testing and shall supply written procedures on the operation and maintenance of the treatment system.

8.3.2 RSSCT Operation

The RSSCT shall be designed using scaling equations derived based on proportional diffusivity assumptions. The design equations for RSSCTs are included in the *Granular Activated Carbon Precursor Removal Studies* section of the *ICR Manual for Bench- and Pilot-Scale Treatment Studies* (USEPA, 1996). The GAC used for the RSSCT shall be a representative sample of unused virgin or reactivated GAC used in the package treatment plant. The RSSCT shall be designed to simulate the EBCT utilized in the package treatment plant.

Various sources for the influent water to be used for the RSSCT studies are possible. If pretreatment modules (e.g. coagulation and sand filtration) are included prior to GAC as a part of the package treatment plant, then this water may be sampled during steady-state operation of these treatment steps has been reached and used as influent to the RSSCT. An existing full-scale water treatment system may also be sampled if treatment steps and DBP precursor removal is representative of that achieved by the package plant. This would allow for the sampling of different water sources and qualities without necessitating transportation, set-up, and operation of the package plant to generate the RSSCT influent water. Alternatively, raw water may be sampled and batch treated under conditions that simulate treatment and DBP precursor removal by the package plant prior to GAC adsorption. In all cases, bench-scale filtration of the RSSCT influent water through a pre-rinsed 1.0-µm glass fiber cartridge filter is required.

It is preferable that the batch influent collected for the RSSCT be large enough to provide a water source of constant water quality for the duration of each RSSCT run. The influent water sampling frequency for the RSSCT is based on a minimum number of samples taken per water batch spaced evenly over the RSSCT run. If more than one

water batch is sampled for a RSSCT study, than influent sampling requirements will increase.

Depending on design and run time, an RSSCT typically requires 100 to 300 L of influent water. The *Granular Activated Carbon Precursor Removal Studies* section of the *ICR Manual for Bench- and Pilot-Scale Treatment Studies* (Treatment Studies Manual) contains guidance in Sections 5.1, 5.2, and 5.3 regarding RSSCT design, operation, and monitoring. The procedures contained in the Treatment Studies Manual shall be followed when performing RSSCTs, with the following exceptions:

1. Design of the RSSCT shall be based on the actual EBCT utilized for GAC adsorption in the package plant. The Treatment Studies Manual specifies that RSSCTs be designed with full-scale equivalent EBCTs of 10 and 20 minutes. For verification testing, RSSCTs must be designed based on the package plant GAC contactor EBCT under normal operating conditions.
2. The RSSCT influent water should ideally be sampled from the package plant after all treatment steps that remove DBP precursors but prior to GAC adsorption. If water samples are taken from an existing water treatment plant, then all treatment steps performed on and chemicals added to the water sample must be representative of the package treatment plant, including prechlorination. If raw water is sampled and batch treated in an off-site laboratory, then the batch treatment must simulate the treatment conditions, chemical dosages, and resulting DBP precursor removal of the pretreatment steps in the package treatment plant.
3. The Treatment Studies Manual does not allow chlorine addition as part of the RSSCT influent water pretreatment (prechlorination). It is not necessary to avoid prechlorination for the purposes of Adsorption Capacity Verification Testing. However, the presence of prechlorination will require sample analysis of formed DBPs in the RSSCT influent and effluent before further chlorination testing.
4. Sampling and analytical methods must be performed as described below in the Analytical Schedule section of Adsorption Capacity Verification Testing.
5. The FTO shall specify a run time criteria for each Adsorption Capacity Verification Testing period. Run time criteria can be based on treated water quality conditions, or set to a specific maximum run time. A run time to 70 percent TOC breakthrough, as specified in the Treatment Studies Manual, is not required.
6. Performing quarterly RSSCT sessions to capture seasonal variability for a given water source (as required in the Treatment Studies Manual) is not necessary. However, multiple RSSCT runs on different water sources with varying water qualities may be necessary to verify the Manufacturer's claims made on the ability of the package plant to remove DBP precursors under a range of water quality conditions.

8.4 Analytical Schedule

8.4.1 Operational Data Collection

The FTO shall provide written procedures describing the operational parameters that should be monitored, monitoring points, and the frequency of monitoring. Such operational parameters shall include at a minimum system flow rates and head loss or pressure. The FTO shall include acceptable values and ranges for all operational parameters monitored.

8.4.2 Water Quality Data Collection

During Adsorption Capacity Verification Testing utilizing either the package plant or the RSSCT, the GAC influent (feed) water quality and GAC effluent water quality shall be characterized by analysis of the water quality parameters listed in Table 2.

The sampling frequency described in Table 2 is intended to provide sufficient operational data and to effectively characterize the breakthrough profile of DBP precursors. A minimum of 8 evenly-spaced GAC effluent samples must be analyzed for TOC, UV_{254}, and DBP formation after chlorination under uniform formation conditions (UFC). (See Task 5 for a description of and procedures for UFC chlorination). The DBPs analyzed after UFC chlorination shall be those upon which the manufacturer's claims of package plant performance are based. Additionally, optional analysis of DBPs not included as part of the manufacturer's claim may be analyzed. These DBPs include, but are not limited to, those listed as optional in Table 2. For pretreatment processes that include prechlorination, additional blank or instantaneous DBP samples must be analyzed. By doing so, the breakthrough of DBPs present in the influent to GAC water (preformed DBPs) can be distinguished from the formation of DBPs after further chlorination testing.

In addition to the required UFC chlorination to assess DBP formation as described above, selected site-specific simulated distribution system (SDS) conditions may be used. SDS conditions may be used to evaluate DBP precursor removal by GAC under varying site-specific distribution system conditions, such as a higher temperature or longer residence times. Chlorination under SDS conditions does not replace the required chlorination under UFC conditions.

The exact sampling interval will depend on the length of verification testing. If the verification testing run time is specified by the FTO as a length of time (e.g., 60 days or 60 full-scale equivalent days) then the required number of samples shall be taken in evenly spaced intervals throughout the verification testing period. If verification testing run time is specified by the FTO as an effluent water quality criterion only, then a run time estimate[1] is needed to determine the appropriate sampling interval.

[1]All references to run times in the following discussion are full-scale run times. The discussion is applicable to both full-scale (package plant) and RSSCT studies, but run times need to be scaled down for application to RSSCT studies.

A flow diagram detailing a procedure to generate a run time estimate is shown in Figure 1. This procedure is based on correlating a given GAC effluent TOC concentration to the influent TOC concentration and run time. If an effluent TOC criterion is not given, then the run time estimate is determined by estimating the TOC concentration from the given formed DBP effluent criterion. Specific DBP yields for 10 different water sources are tabulated in Summers et al. (1996), and average specific DBP yields are listed in Table 3. An estimate of the TOC concentration can be obtained by dividing the DBP concentration by the average specific DBP yield.

A correlation has been shown between GAC run time and influent TOC concentration for 28 case studies from 21 different source waters. These studies include bench-, pilot-, and full-scale breakthrough profiles using bituminous-based GAC for waters with influent TOC concentrations between 1 and 11 mg/L and initial pH values between 7 and 8. Surface and ground waters from across the U.S. are included in the data set comprising the correlation. A best fit of the data is described by Equation 1 (Summers et al., 1994; Hooper et al., 1996):

$$BV_{50} = \frac{18{,}000}{TOC_0} \qquad r^2 = 0.86 \qquad (1)$$

where BV_{50} is the number of bed volumes treated to 50 percent TOC breakthrough and TOC_0 is the influent TOC concentration (mg/L). The run time to 50 percent TOC breakthrough, t_{50}, is calculated by multiplying BV_{50} and the EBCT:

$$BV_{50} \times EBCT = t_{50} \qquad (2)$$

Using Equations 1 and 2, t_{50} can now be calculated:

$$t_{50} = \frac{BV_{50} * EBCT\,(min)}{1440\,(min/day)} \qquad (3)$$

where t_{50} is the run time to 50 percent TOC breakthrough (days) and 1440 is a conversion factor between units of minutes and days. Substituting into Equation 1:

$$t_{50} = \frac{12.5 * EBCT}{TOC_0} \qquad (4)$$

Equation 4 is only applicable for a run time estimate if the run time criteria is an effluent TOC concentration near 50 percent of the influent TOC concentration. When the run time criteria yields an effluent TOC concentration other than 50 percent of the influent TOC concentration, Equation 4 can still be used, by introduction of a constant:

$$t_P = \frac{12.5 * A_P * EBCT}{TOC_0} \quad (5)$$

where t_P is run time to percent breakthrough P, and A_P is a constant whose value is determined from Table 4 or Figure 2, and is based on the percent TOC breakthrough goal. For example, given a GAC run time criteria of an effluent TOC concentration of 2.4 mg/L, corresponding to 60 percent TOC breakthrough in a system with a TOC_0 of 4.0 mg/L, a value for A_P of 1.28 should be used in Equation 5. For an EBCT of 15 min, this would yield an estimated run time of 60 days (full-scale or full-scale equivalent).

Once a run time estimate has been determined, sampling events for TOC, UV_{254}, and DBP formation assessment shall be evenly spaced throughout the run time, after an initial sampling one day after the start of operation. The sampling interval can be calculated by Equation 6:

$$I_S = \frac{t_P - 1}{n_S - 1} \quad (6)$$

where I_S is the sampling interval (days) and n_S is the number of samples. For RSSCTs, the sampling interval must be scaled down by the appropriate factor to yield a laboratory sampling interval. In addition, initial sampling should begin after no less than one hour of RSSCT operation.

The above procedure has been developed to provide an estimate of GAC run time based on influent water quality and FTO's run time criterion, assuming a water quality with average DBP precursor adsorbability, average specific DBP yield, the use of a bituminous based GAC, and an influent pH between 7 and 8. Run times may exceed the estimate for highly adsorbable water sources or influent pH values below 6.5. If no maximum run time is stipulated by the FTO, then verification testing should proceed until the effluent water quality criterion is met or exceeded, regardless of the calculated estimated run time. It may be prudent to include a 20 percent safety factor in the run time estimate calculation when the relative adsorbability of the water source is unknown.

Additional parameters or more frequent analysis of the some of the above parameters may be required to ensure that pretreatment steps included prior to GAC are functioning properly. Additional sampling requirements, acceptable analytical methods, and sampling frequencies shall be provided by the FTO.

The first sampling event for each required analyte shall be performed one day after operation start-up, (one hour for RSSCTs) and then by the frequency given. Although many parameters may be analyzed off-site, pH, temperature, and turbidity must be analyzed on-site. It is recommended that UV_{254} be also analyzed on-site. Samples to be assessed for DBP formation should be chlorinated as soon as possible after the sampling event. In general, samples should be chlorinated no later than 5 days after each sample was taken. The water quality parameters in Table 2 are listed to provide State drinking water regulatory agencies with background data on the quality of the feed water being

treated and the quality of the treated water. These data are to be collected to enhance the acceptability of the Adsorption Capacity Verification Testing to a wide range of drinking water regulatory agencies.

8.5 Evaluation Criteria and Minimum Reporting Requirements

8.5.1 Control of TOC, UV_{254}, and DBP formation

Plot breakthrough curves (GAC effluent concentrations versus run time) for TOC, UV_{254}, and UFC-DBP concentrations. Include plotted GAC influent parameter concentrations over run time on the same plot. Calculate and tabulate average influent parameter concentrations. Compare DBP precursor removal with Manufacturer-specified removal goals.

8.5.2 Process control

Tabulate or plot GAC influent and effluent temperature, pH, and turbidity. Include GAC influent and effluent average, standard deviation, and percent standard deviation for each analyte. Tabulate GAC influent alkalinity, calcium hardness, and total hardness. Include average, standard deviation, and percent standard deviation for each analyte.

9.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

9.1 Introduction

During each day of verification testing, operating conditions shall be documented. This shall include descriptions of any pretreatment processes and their operating conditions. In addition, the performance of the water treatment equipment shall be documented, including rate of filter head loss gain and frequency and duration of filter washing for GAC contactors operated as a filter-adsorber. The volumetric flow rate through a GAC contactor is a critical parameter, and must be monitored and documented. GAC performance is affected by the EBCT, which varies directly with the volumetric flow rate through the contactor.

9.2 Experimental Objectives

The objective of this task is to accurately and fully document the operation conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

This task shall be performed in conjunction with System Integrity Verification Testing. This task shall also be performed in conjunction with Adsorption Capacity Verification Testing, when Adsorption Capacity Verification Testing is conducted using the package treatment plant. When Adsorption Capacity Verification Testing is conducted using RSSCTs, a summary description of

the pretreatment applied to the water sampled for each RSSCT session shall be provided, including pretreatment steps, chemical dosages, flow rates, and any other relevant design and process information. In addition, a design summary of the RSSCT shall also be provided, including, but not limited to, particle size, scaling factor, column diameter, bed depth, volumetric flow rate, EBCT, velocity, minimum Reynolds number, porosity, dry bed density, and mass of GAC utilized.

9.3 Work Plan

During each day of verification testing (both System Integrity Verification Testing and Adsorption Capacity Verification Testing), treatment equipment operating parameters for both pretreatment and GAC adsorption shall be monitored and recorded on a routine basis. This shall include a complete description of pretreatment chemistry; mixing and flocculation intensities, if applicable; operating parameters for clarification ahead of filtration, if applicable; rate of flow; and filtration rate. Data on filter head loss and backwashing shall be collected for either sand media prefilter or GAC filter-adsorber.

Electrical energy consumed by the treatment equipment shall be measured, or as an alternative, the aggregate horsepower of all motors supplied with the equipment could be used to develop an estimate of the maximum power consumption during operation. Performance shall be evaluated to develop data on chemical dosages needed and on energy needed for operation of the process train being tested.

A complete description of each treatment process shall be given, with data on points of chemical addition, and volume and detention time of each process basin at rated flow, if applicable. Data on the GAC contactor shall be provided and shall include the EBCT, depth, effective size, and uniformity coefficient of each layer of GAC and support material. The type and source of GAC used and the type of support material used shall be stated.

9.4 Schedule

Table 5 presents the schedule for observing and recording package plant operating and performance data. The schedule applies to both System Integrity Verification Testing and Adsorption Capacity Verification Testing using the package plant. For Adsorption Capacity Verification Testing conducted using the RSSCT, Table 6 presents the schedule for observing and recording RSSCT operating and performance data.

9.5 Evaluation Criteria

Where applicable, the data developed from this task shall be compared to Manufacturer's statements of performance capabilities. If no relevant statement of performance capability exists, results of operating conditions and performance data will be tabulated for inclusion in the Verification Report.

10.0 TASK 4: DATA MANAGEMENT

10.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software and manual recording of operational parameters for the GAC adsorption and pretreatment equipment on a daily basis.

10.2 Experimental Objectives

The Objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data to NSF for verification purposes.

10.3 Work Plan

The following protocol has been developed for data handling and data verification by the Field Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of GAC contactor operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the Field Testing Organization at least once per week during each quarterly one-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected

version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (i.e., System Integrity Verification Testing runs or Adsorption Capacity Verification Testing runs) shall be assigned a unique run number which will then be permanently associated to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA- accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.0 TASK 5: QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

11.1 Introduction

Quality assurance and quality control of the operation of the water treatment system, GAC contactors, RSSCTs, and the measured water quality parameters shall be maintained during the verification testing program.

11.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

11.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk through during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to confirm that any chemicals are being fed at the defined flow rate into a flowstream that is operating at the expected flow rate, such that the chemical concentrations are correct. In-line monitoring equipment such as flowmeters, etc. shall be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods or specified by the FTO.

It is extremely important that system flow rates be maintained at set values and monitored frequently. Doing so allows a constant and known EBCT to be maintained in the GAC contactor or RSSCT. GAC performance is directly affected by the EBCT, which in turn is proportional to the volumetric flow rate through the contactor or RSSCT. Therefore, an important QA/QC objective shall be the maintenance of a constant volumetric flow rate through the GAC contactor

or RSSCT by frequent monitoring and documentation. Documentation shall include an average and standard deviation of recorded flow rates through the GAC contactor or RSSCT.

11.3.1 Daily QA/QC Verifications:

- Chemical feed pump flow rates (verified volumetrically over a specific period of time)
- In-line turbidimeter flow rates (verified volumetrically over a specific period of time, if employed)
- In-line turbidimeter readings checked against a properly calibrated bench model.
- Package plant GAC contactor flow rate (verified volumetrically every two hours when staffed; at least twice daily)
- RSSCT column flow rate (verified volumetrically every two hours when staffed; at least three times daily)

11.3.2 QA/QC Verifications for Each Testing Period:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow rate volumetrically to avoid erroneous readings)
- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)

11.4 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of GAC influent and effluent water quality are described in the section below. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

11.4.1 pH

Analyses for pH shall be performed according to Standard Method 4500-H^+ or EPA Method 150.1/150.2. A two-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss with the atmosphere.

11.4.2 Temperature

Temperature shall be analyzed according to *Standard Method* 2550. The thermometer shall have a scale marked for every 0.1 ^{o}C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1^{o}C to +51^{o}C, subdivided in 0.1^{o} increments, would be appropriate for this work.)

11.4.3 UV_{254} Absorbance

Analysis of UV_{254} shall be performed according to *Standard Method* 5910 B. The maximum allowable holding time for *Standard Method* 5910 B is 48 hours. Therefore, it is recommended that UV_{254} samples be analyzed on-site by the Field Testing Organization with an UV spectrophotometer at 254 nm.

11.4.4 Turbidity

Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters are recommended for measurement of turbidity in the treated water, and either an in-line or a bench-top turbidimeter may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Bench-top Turbidimeters: Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of pilot plant operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 Nephlometric Turbidity Units (NTU). Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down

the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples dial cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

In-line Turbidimeters: In-line turbidimeters must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

11.5 Chemical and Biological Samples Shipped Off-Site for Analyses

The analytical methods that shall be used during testing for chemical and biological samples that are shipped off-site for analyses are described in the section below.

11.5.1 Inorganic Samples

Inorganic chemical samples shall be collected and preserved in accordance with *Standard Method* 3010B, if applicable, paying particular attention to the sources of contamination as outlined in *Standard Method* 3010C. The samples shall be refrigerated at approximately 4^{o}C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4^{o}C during shipment. Samples shall be held and processed for analysis by a State or EPA-accredited laboratory in accordance with *Standard Methods*. The laboratory shall keep the samples at approximately 4^{o}C until initiation of analysis.

Alkalinity analyses shall be performed according to Standard Method 2320 B. Calcium hardness analyses shall be performed according to Standard Method 3500-Ca D. Total hardness analyses shall be performed according to Standard Method 2340 C. In accordance with Standard Method 2340 B, total hardness may also be analyzed by addition of separate analyses of calcium and magnesium. Calcium and magnesium may be analyzed by Standard Method 3111B, Standard Method 3120 or EPA Method 200.7.

11.5.2 Organic Parameters: Total organic carbon (TOC)

TOC analyses shall be performed according to Standard Method 5310 C. Samples for analysis of TOC shall be collected in amber glass bottles with TFE-lined septa supplied by the State or EPA accredited laboratory. The appropriate preservative as indicated by the State or EPA accredited laboratory shall be added. The samples shall be shipped overnight with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by the State or EPA accredited laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of 4°C until initiation of analysis.

11.5.3 DBP Samples

DBPs samples shall be collected, preserved (if applicable), held, and analyzed in accordance with the appropriate Standard Method.

11.6 Tests and Data Specific to GAC Type Evaluated

The GAC type used for testing shall be described by providing data on the GAC type characteristics and tests listed in Table 7. All analyses shall be performed according to procedures outlined in AWWA B-604.

11.7 DBP Precursor Assessment Test Protocol

During Adsorption Capacity Verification Testing, GAC adsorption of DBP precursors shall be assessed by simulating full-scale disinfection and sampling for DBPs. This is accomplished by spiking water samples with disinfectant and holding the spiked samples headspace-free in the dark at a designated temperature, pH, and contact time. Both GAC influent and effluent samples are tested, thus allowing for DBP precursor removal through GAC contactors to be assessed.

In practice, drinking water utilities and researchers often test for DBP formation under site-specific simulated distribution system (SDS) conditions. Under SDS conditions, the disinfectant dose, disinfectant residual, contact time, temperature, and pH utilized are representative a particular distribution system. For Adsorption Capacity Verification Testing, DBP formation shall be assessed under uniform formation conditions (UFC) with free chlorine as disinfectant. The UFC test is a free chlorine residual-based test that uses constant chlorination conditions representative of average distribution system conditions (Summers et al., 1996). The constant chlorination conditions used will facilitate DBP precursor control comparisons between Adsorption Capacity Verification Testing sessions performed on different water sources and different package plants. The UFC test conditions are:

- Incubation time: 24 ± 1 hours
- Incubation temperature: 20.0 ± 1.0 °C
- Buffered pH: 8.0 ± 0.2
- 24-hr free chlorine residual: 1.0 ± 0.4 mg/L as Cl_2

An important aspect of the UFC test is that it is based on a constant free chlorine residual after the 24-hour incubation time. However, free chlorine demand (chlorine dose subtracted from free chlorine residual) varies with water sources and with treatment, based on differences in inorganic and organic demand. In general, as TOC increases, free chlorine demand increases.

Some difficulty may be encountered when attempting to achieve the target UFC free chlorine residual for GAC effluent samples, as the unsteady-state behavior of GAC is reflected in free chlorine demand. This difficulty is heightened by the presence of inorganic compounds, which may exert a significant free chlorine demand, and are not removed by GAC. If inorganic demand is significant, then it may account for a large fraction of the overall free chlorine demand present at the beginning of the breakthrough curve, when organic free chlorine demand is well removed by the GAC. As run time increases, organic demand increases while inorganic free chlorine demand remains constant, thus diminishing the effect of inorganic demand on overall free chlorine demand.

For GAC effluent samples, free chlorine demand usually correlates well with TOC concentration, and this relationship can be utilized to aid in predicting free chlorine demand, without directly accounting for inorganic demand. If prior experience with GAC adsorption relating free chlorine demand to TOC for a particular water source and pretreatment is not available, a method has been developed that simulates breakthrough conditions to obtain a relationship between free chlorine demand and TOC throughout GAC contactor run time. The method is published in the Treatment Studies Manual (USEPA, 1996a) and an adaptation has been included in Appendix A.

Alternatively, a sample to be chlorinated may be split into three incubation bottles and chlorinated under UFC. The chlorine dose is varied across the three samples, with the goal of obtaining at least one sample with the targeted 24-hour free chlorine residual of 1.0 ± 0.4 mg/L as Cl_2. After 24 hours, the free chlorine residual is measured in all three samples, and the sample with an acceptable free chlorine residual is also sampled for the FTO-specified DBP analyses. When the approximate chlorine dose is known, it is also acceptable to chlorinate a small aliquot of the sample under UFC, and to measure only the free chlorine residual of the aliquot after 24 hours. Based on the measured free chlorine demand, adjustments are made, if necessary, to the required chlorine dose for UFC, and the rest sample is chlorinated.

During UFC chlorination, the following parameters shall be recorded: chlorine dose (mg/L as Cl_2); free chlorine residual (mg/L as Cl_2); initial sample pH, just prior to chlorine addition; final sample pH, at end of incubation period; incubation temperature (°C); incubation time (hours).

The chlorine stock solution shall be standardized according to Standard Method 4500-Cl B. The stock solution is typically prepared at a concentration 500 to 1000 times stronger than the dose required to minimize dilution errors. Free chlorine residual shall be analyzed according to Standard Method 4500-Cl D, 4500-Cl F, 4500-Cl G, or 4500-Cl H. Prior to and after chlorination, pH shall be analyzed according to Standard Method 4500-H^+ B or EPA Method 150.1/150.2. Temperature shall be analyzed according to Standard Method 2550 B.

DBP analysis shall be performed by a state or EPA accredited laboratory according to Standard Methods and EPA procedures appropriate for the designated DBPs. The bottles used to sample for DBPs shall be prepared by the state or EPA accredited laboratory, and shall contain all required quenching agents and preservatives.

A standard operating procedure for UFC chlorination has been published (Summers et al., 1996) and is contained in Appendix B.

12.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied operations and maintenance (O&M) manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for the evaluation of O&M manuals for package plants employing granular activated carbon for DBP precursor removal

12.1 Maintenance

The manufacturer should provide readily understood information on the required or recommended maintenance schedule for each piece of operating equipment including, but not limited to:

- pumps
- valves
- all instruments, such as turbidimeters or pH meters
- water meters, if provided
- pressure or headloss gauges

The manufacturer should provide readily understood information on the required or recommended maintenance schedule for non-mechanical or non-electrical equipment including, but not limited to:

- GAC contactor vessels
- feed lines
- manual valves

The manufacturer should provide readily understood information on the following procedures:

- spent GAC removal and replacement

12.2 Operation

The manufacturer should provide readily understood information on the required or recommended procedures related to the proper operation of the package plant equipment, including, but not limited to, the following aspects:

GAC filtration:

- control of filtration rate

- observation and measurement of head loss during filter run (only applicable to GAC filter-adsorbers)

Backwashing (only applicable to GAC filter-adsorbers):
- determination of end of filter-adsorber run
- use of auxiliary water scour (surface wash) or air scour
- start of backwash
- appropriate backwash rates and times
- conclusion of backwashing
- return of contactor to service

Monitoring and observing operation:
- measuring feed water flow rates
- feed water turbidity
- filtered water turbidity
- contactor head loss
- procedures to follow upon turbidity breakthrough (only applicable to GAC filter-adsorbers)

13.0 REFERENCES

Hooper, S.M., R.S. Summers, G. Solarik, and S. Hong. 1996. GAC Performance for DBP Control: Effect of Influent Concentration, Seasonal Variation, and Pretreatment. In *Proc. of the AWWA Annual Conference*, Toronto, Ontario, Canada.

Standard Methods for the Examination of Water and Wastewater. 1995. 19th edition. APHA, AWWA, and WEF, Washington, D.C.

Summers, R.S., S.M. Hooper, H.M. Shukairy, G. Solarik, and D.M. Owen. 1996. Assessing DBP Yield: Uniform Formation Conditions. *Journal AWWA* (88:6:80).

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USEPA. 1996a. ICR Manual for Bench- and Pilot-Scale Treatment Studies. Technical Support Division, Office of Ground Water and Drinking Water, U.S. Environmental Protection Agency.

USEPA. 1996b. DBP/ICR Analytical Methods Manual. Technical Support Division, Office of Ground Water and Drinking Water, U.S. Environmental Protection Agency.

Table 1.
Required water quality analyses and minimum sample frequencies for System Integrity Verification Testing

Parameter	Frequency	Standard Method[a]	EPA Method[b]
GAC Influent			
Temperature	Weekly	2550 B	
pH	Once daily	4500-H^+ B	150.1 / 150.2
Alkalinity	Weekly	2320 B	
Total hardness	Weekly	2340 C	
Calcium hardness	Weekly	3500-Ca D	
Total organic carbon	Three samples evenly spaced over testing period	5310 C	
UV absorbance at 254 nm	Three samples evenly spaced over testing period	5910 B	
Turbidity	Filter-adsorber: continuous, and daily at bench-top to check continuous turbidimeter Post-filter adsorber: daily	2130 B / Method 2	180.1
GAC Effluent			
Temperature	Weekly	2550 B	
pH	Once daily	4500-H^+ B	150.1 / 150.2
Total organic carbon	Three samples evenly spaced over testing period	5310 C	
UV absorbance at 254 nm	Three samples evenly spaced over testing period	5910 B	
Turbidity	Filter-adsorber: continuous, and daily at bench to check continuous turbidimeters Post-filter adsorber: daily	2130 B / Method 2	180.1

Notes:

[a] Standard Methods Source: 19th Edition of Standard Methods for the Examination of Water and Wastewater, 1995, American Water Works Association.

[b] EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Table 2.
Required water quality analyses and minimum sample frequencies for Adsorption Capacity Verification Testing

Parameter	Frequency	Standard Method[a]	EPA Method[b]
GAC Influent			
Temperature	Package plant: Weekly RSSCT: 3 evenly-spaced samples per water batch	2550 B	
pH	Package plant: Twice weekly RSSCT: 3 evenly-spaced samples per water batch	4500-H^+ B	150.1 / 150.2
Alkalinity	Package plant: 5 evenly-spaced sample events RSSCT: 3 evenly-spaced samples per water batch	2320 B	
Total hardness	Package plant: 5 evenly-spaced sample events RSSCT: 3 evenly-spaced samples per water batch	2340 C	
Calcium hardness	Package plant: 5 evenly-spaced sample events RSSCT: 3 evenly-spaced samples per water batch	3500-Ca D	
Total organic carbon	Package plant: 8 sampling events[c] RSSCT: 3 sampling events[d]	5310 C	
UV absorbance at 254 nm	Package plant: 8 sampling events[c] RSSCT: 3 sampling events[d]	5910 B	
Turbidity	Package plant, filter adsorber: continuous, and daily at bench to check continuous turbidimeters Package plant, post-filter adsorber: daily RSSCT: 3 evenly-spaced samples per water batch	2130 B / Method 2	180.1
Ammonia (optional)	Package plant: 5 evenly-spaced sample events RSSCT: 3 evenly-spaced samples per water batch		
UFC-DBPs	Package plant: 8 sampling events[c] RSSCT: 3 sampling events[d]		
Optional DBPs (if not already analyzed)[e] including THMs, HAA, TOX, chloral hydrate, chloropicrin, and haloacetonitriles	Package plant: 8 sampling events[c] RSSCT: 3 sampling events[d]		
Preformed or instantaneous DBPs (if applicable)[f]	Package plant: 8 sampling events[c] RSSCT: 3 sampling events[d]		
Bromide	Package plant: 8 sampling events[c] RSSCT: 3 sampling events[d]		300.0

GAC Effluent			
Temperature	Weekly	2550 B	
pH	Twice weekly	4500-H^+ B	150.1 / 150.2
Total organic carbon	8 sampling events	5310 C	
UV absorbance at 254 nm	8 sampling events	5910 B	
Turbidity	Package plant filter adsorber: continuous, and daily at bench to check continuous turbidimeters Package plant post-filter adsorber: daily RSSCT: Not required	2130 B / Method 2	180.1
Ammonia (optional)	Package plant: 5 evenly-spaced sample events RSSCT: 3 evenly-spaced samples per water batch		
UFC-DBPs	8 sampling events		
Optional DBPs (if not already analyzed)[e] including THMs, HAA, TOX, chloral hydrate, chloropicrin, and haloacetonitriles	8 sampling events		
Preformed or instantaneous DBPs (if applicable)[f]	8 sampling events		

Notes:

[a] Standard Methods Source: 19th Edition of Standard Methods for the Examination of Water and Wastewater, 1995, American Water Works Association.

[b] EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

[c] Influent sampling shall occur at approximately the same time as effluent sampling for each parameter during package plant operation.

[d] RSSCT influent sampling shall be evenly spaced for each batch of water used throughout the run time.

[e] DBPs included as part of manufacturer's claim are not optional and must be analyzed. If not already analyzed, other optional DBPs may be analyzed. These DBPs include, but are not limited to, those listed.

[f] If pretreatment includes prechlorination, then the concentrations of preformed DBPs must be determined by analyzing blank or instantaneous DBP samples as described in section 8-4.

Table 3.
Average DBP specific yield under UFC (Summers et al., 1996)

UFC-DBP	Average Specific Yield (µg DBP/mg TOC)
TTHM	29
HAA6	19
TOX	99

Table 4.
Values of A_P to be used in Equation 5 for percent TOC breakthrough criteria

Effluent TOC concentration as a percent (P) of influent TOC concentration (%)	A_p
20	0.56
30	0.68
40	0.80
50	1.00
60	1.28
70	1.80

Table 5.
Schedule for observing and recording package plant operating and performance data

Operational parameter	Action
Feed water and GAC contactor volumetric flow rate	When staffed, check and record every two hours, adjust when >5% above or below target. Record before and after adjustment.
GAC contactor head loss	Filter-adsorber: record initial clean bed total head loss at start of filter-adsorber run and record total head loss every two hours, when staffed. Post-filter adsorber: record daily
Filter backwash (filter-adsorber only)	Record time and duration of each filter washing. Record volume used to wash filter.
Electric power	Record meter daily
Chemicals used	Record name of chemical, supplier, commercial strength, dilution used for stock solution to be fed (if diluted) for all chemicals fed during treatment
Chemical feed volume and dosage	Check and record every 2 hours. Refill as needed and note volumes and times of refill
RPM of rapid mix and flocculator (if applicable)	Check daily and record
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day. Any stoppage of flow to the contactors shall be recorded. Flow stoppage that exceeds 2 hour per 24-hour period or 7 hours per week shall be accounted for by not including it in the cumulative operation time.

Table 6.
Schedule for observing and recording RSSCT operating and performance data

Operational parameter	Action
RSSCT flow rate	When staffed, check and record every two hours, adjust when >5% above or below target. Record before and after adjustment.
System pressure	When staffed, record every two hours
Hours operated per day	Record in log book at end of day or at beginning of first shift on the following work day. Any stoppage of flow to the RSSCT shall be recorded. Flow stoppage that exceeds 30 minutes per 24-hour period shall be accounted for by not including it in the cumulative operation time.

Table 7.
Tests and data specific to GAC type evaluated

Data	**Parameter**
Raw material used to make GAC:	
Method of manufacture:	Chemical activation Thermal activation Agglomerated and activated Direct activation
Reactivated carbon:	Chemical activation Thermal activation Agglomerated Direct activation
Physical and chemical characteristics:*	Iodine number Percent ash Water soluble ash Abrasion number Moisture (weight %) Particle size Sieve size, US sieve series Effective size Uniformity coefficient

*Tests used to determine values for physical and chemical characteristics must be performed in accordance with procedures outlined in AWWA B-604.

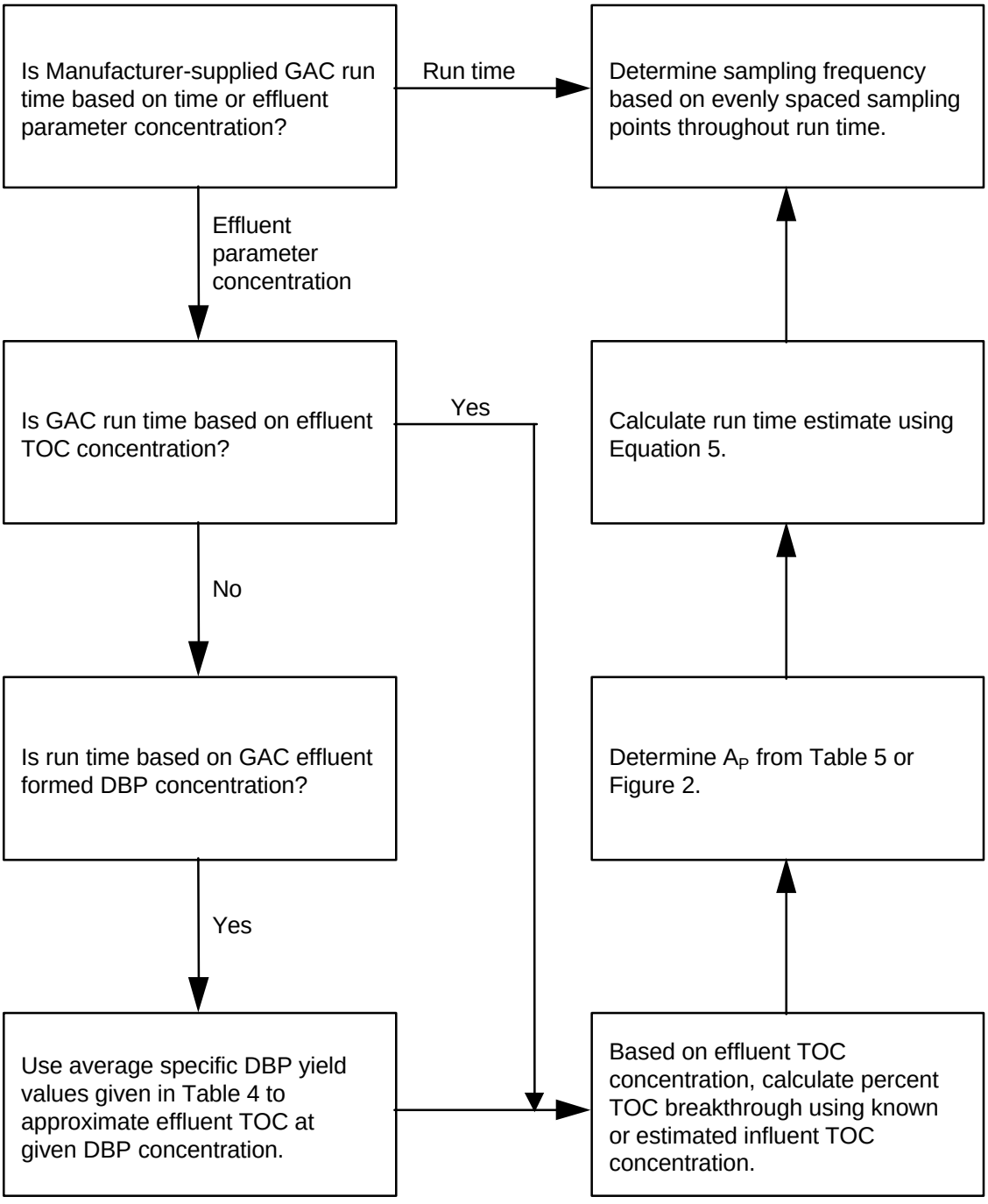

Figure 1.
Flow chart for determination of sampling frequency during Adsorption Capacity Verification Testing

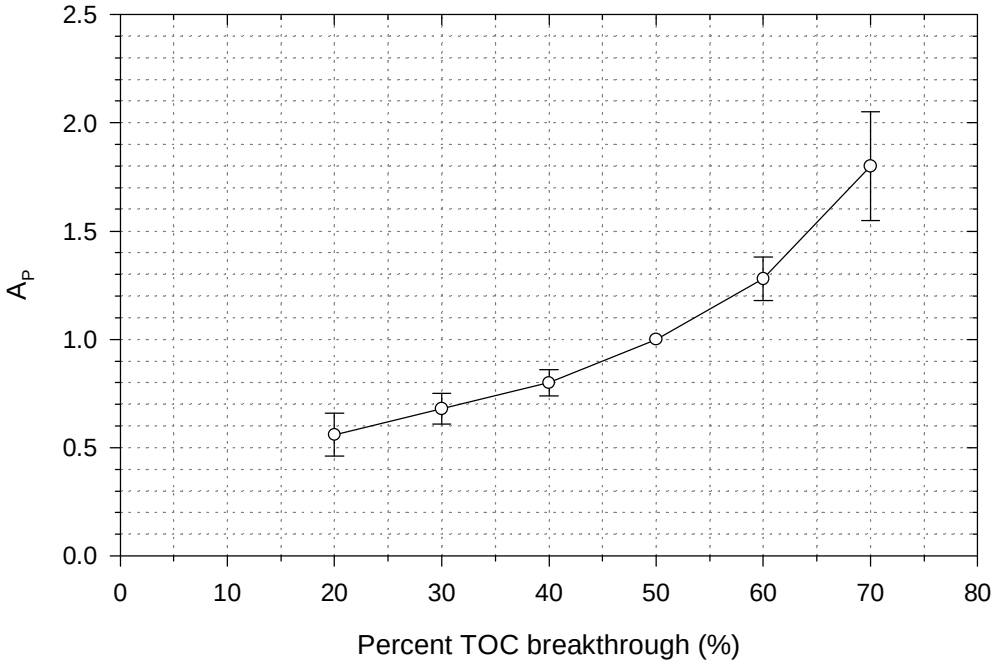

Figure 2.
Values of A_P as a function of percent TOC breakthrough

Appendix A

Preliminary UFC Free chlorine Demand Study

If prior experience relating free chlorine demand to TOC for a GAC treated water from a specific source and with specific pretreatment is not available, a method has been developed that simulates breakthrough conditions to obtain a relationship between free chlorine demand and TOC, without requiring the operation of a separate GAC column. The method is termed a dilution study, and is based on diluting the GAC influent water to several intermediate TOC concentrations and investigating the free chlorine demand of these dilution samples. While TOC is diluted, the inorganic background should not be affected by the procedure. This is accomplished by diluting the GAC influent with water taken from the GAC effluent very early in GAC operation, so that natural organic matter removal is maximized and inorganic constituents are conserved.

The following outlines the dilution study procedure. Two aliquots of water are needed: one from the GAC influent, and one from the GAC effluent (dilution aliquot) taken as early as possible in the study, so that natural organic matter removal is maximized. The two aliquots are systematically mixed to form seven dilution samples with varying composition, as outlined in Table A-1. The volume of each dilution sample should be sufficient for TOC and UV_{254} analysis and to chlorinate at three doses for UFC free chlorine demand analysis. The total volume of the dilution aliquot is 50 percent greater than the required volume of GAC influent water. After mixing, each of the seven dilution samples are analyzed for TOC and UV_{254}. Three chlorine doses for each dilution sample are determined by multiplying the measured TOC of the dilution sample (TOC_{ds}) by the respective free chlorine demand (CD) to TOC ratio (CD:TOC) listed in Table A-1 and adding to these values the free chlorine residual required for the UFC test.

$$\text{Chlorine dose} = TOC_{ds}(\text{CD:TOC}) + \text{target free chlorine residual}$$

Therefore, the chlorine dose for each dilution sample is bracketed with the goal of achieving a residual in one of the three samples that is near the target free chlorine residual. Note that at low TOC concentrations (dilution samples 1 through 3), a wide range of free chlorine demand to TOC ratios are used, because inorganic demand may dominate.

Dilution study chlorination should be conducted under UFC. The free chlorine demand calculated from the dose that yields a residual nearest to the target residual for each dilution sample is used to generate a plot of free chlorine demand against TOC. Thus, a correlation is obtained between TOC and free chlorine demand, which can be used to estimate free chlorine demand for GAC effluent samples, after TOC analysis.

Prior to chlorination for DBP analysis, it is recommended that a small aliquot from each effluent sample be chlorinated at a dose based on the dilution study results and analyzed only for free chlorine demand. Adjustments in the chlorine dose can then be made if needed, since the adsorbability or chlorine reactivity can naturally change with time.

Table A-1 .
Dilution study parameters

Sample number	Influent water (%)	Dilution water (%)	CD:TOC (mg Cl_2/mg TOC)		
			Low	Target	High
1	0	100	0.5	2.5	5.0
2	10	90	0.5	2.0	3.5
3	20	80	0.5	1.5	2.5
4	35	65	0.3	1.3	2.3
5	50	50	0.3	1.0	1.7
6	70	30	0.3	1.0	1.7
7	100	0	0.3	1.0	1.7

Appendix B

Uniform Formation Conditions (UFC) for DBP Formation
Standard Operating Procedure (Summers et al., 1996)

Uniform Formation Conditions:

pH:	8.0 ± 0.2
temperature:	20.0 ± 1.0°C
incubation time:	24 ± 1 hr
free chlorine residual:	1.0 ± 0.4 mg/L as free chlorine after 24 hr

Preliminary Study:

A 24-hour free chlorine demand study on the water sample may be required before dosing under UFC to determine the applied dose that will yield a free chlorine residual of 1.0 mg/L after 24 hours (procedure described below).

Materials:

- chlorine demand-free glassware
- pH 8.0 borate buffer
- pH 8.0 combined hypochlorite/buffer dosing solution

Methods:

Chlorine demand-free glassware:
Incubation bottles (amber, with TFE-faced caps): soak in detergent (Fisher FL-70, 2%) at least overnight, rinse 4x with hot tap water, 2x with DI water. Place in 10-20 mg/L chlorine solution (made with DI water) for at least 24 hours. Rinse 4x with DI water and then 1-2x with type 1 reagent water (Standard Method 1080 C); dry in 140°C oven at least overnight. Store dosing pipettes in ~50 mg/L Cl_2 (made with type 1 reagent water). Rinse 3x with dosing solution prior to use, and return pipettes to storage in chlorine solution after use.

pH 8.0 borate buffer:
Before dosing, water samples are buffered to pH 8.0 with 2 mL/L borate buffer: 1.0M boric acid (ACS grade) and 0.26M sodium hydroxide (ACS grade) in boiled type 1 reagent water. If necessary, add diluted H_2SO_4 and NaOH by drops to the water samples after the buffer has been added for a final adjustment to pH 8.0. This buffer system is suggested; another buffer system, which does not exert a free chlorine demand and maintains sample pH at 8.0 ± 0.2 is acceptable.

pH 8.0 combined hypochlorite/buffer dosing solution:
A combined hypochlorite/buffer solution (based on method described in Koch et al., "A Simulated Distribution System Trihalomethane Formation Potential Method," 1987 AWWA WQTC) is made by buffering the hypochlorite solution to pH 8.0 with pH 6.7 borate buffer.

- pH 6.7 borate buffer: 1.0M boric acid (ACS grade) and 0.11M sodium hydroxide (ACS grade) in boiled type 1 reagent water

- add pH 6.7 borate buffer to chlorine solution (1000-4000 mg Cl_2/L) to yield a pH 8.0 dosing solution. (A 4-5:1 volume ratio of pH 11.2 hypochlorite solution to pH 6.7 borate buffer has been found to yield a pH 8.0 combined hypochlorite/buffer solution, with an approximately 20% drop in chlorine strength.)

The dosing solution (combined OCl^-/buffer) chlorine strength should allow for a dosing volume of < 0.5% of the water sample volume (e.g. 2.5 mL dosing solution in 1.0 L bottle).

Preliminary study:

Perform a 24-hour free chlorine demand study (buffered at pH 8.0 and incubated in the dark at 20°C as described in the dosing procedure) using a series of three chlorine doses based on Cl_2:TOC ratios of 1.2:1, 1.8:1, and 2.5:1, after adjusting for inorganic demand. From the results of these tests, the chlorine dose for UFC is selected to yield a 24-hour residual of 1.0 mg/L free chlorine.

Dosing procedure:

1. add 2.0 mL/L pH 8.0 borate buffer to water sample
2. adjust to pH 8.0 with diluted H_2SO_4 and NaOH (if necessary)
3. fill incubation bottle 75 - 90 percent full with buffered water sample
4. dose with combined hypochlorite/buffer solution holding pipette just above water surface
5. cap bottle, invert twice
6. fill to top with buffered water sample and cap headspace-free
7. invert 10 times
8. incubate in dark at 20.0°C for 24 hours
9. after incubation period, measure free chlorine residual, pH, and sample for DBPs.

The following elements shall be considered for UFC chlorination:

A. How close did experimental measurements of chlorination conditions (chlorine residual, incubation time, incubation pH, etc.) match the target conditions? Were they within the acceptable +/- range given for the UFC test?
B. How much time elapsed between sampling and chlorination? A good guide is that samples should be chlorinated as soon as possible, but not more than 5 days after sample collection.
C. After sampling, but prior to chlorination, samples should be stored in the dark at 4 degrees Celsius.

D. When possible, DBPs should be sampled before chlorine residual and pH are measured.
E. When sampling for more than one DBP, order of sampling should be based on relative volatility of compounds to be analyzed, with those most volatile sampled first. For example, THMs, TOX, and HAAs should be sampled in that order.